WHY THE UNIVERSE HAS NO CENTER p. 28

MAY 2013

Astronomy®

The world's best-selling astronomy magazine

How life survived an early faint Sun

Long ago, water flowed and life emerged despite weak sunlight p. 22

The science behind UFOs p. 44

Explore 11 spring binocular gems p. 64

Target Hubble's best galaxies p. 50

Dennis Mammana's cosmic portraits p. 56

www.Astronomy.com

Vol. 41 • Issue 5

BONUS ONLINE CONTENT CODE p. 4

PLUS!

Online Content Code: ASY1305
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content

CONTENTS

MAY 2013
VOL. 41, NO. 5

RON MILLER FOR ASTRONOMY

ON THE COVER
Liquid water and single-celled life managed to survive on Earth more than 3.5 billion years ago despite a far less luminous Sun than today's.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

Visit **Astronomy.com/toc** for bonus material — it's exclusive to *Astronomy* magazine subscribers.

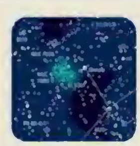
Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Publishing Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Canada Publication Mail Agreement #40010760.

ONLINE FAVORITES >>

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

News
The latest updates from the science and hobby

Trips & Tours
Travel the world with the staff of *Astronomy*



Celestial Portraits
Explore each of the 88 constellations

Extra Content
More in-depth articles on popular topics

FROM THE **EDITOR**

BY DAVID J. EICHER

A cosmic close call

All of us were amazed by the unprecedented meteorite fall that occurred in Russia in February. Strangely, it took place just 15 hours before the close passage to Earth of a near-Earth object (NEO), the 150-foot-diameter (45 meters) asteroid 2012 DA_{14}. The two events were clearly unrelated because the orbital dynamics of the bodies did not match. 2012 DA_{14}'s close brush with Earth's surface carried it just 17,200 miles (27,700 kilometers) above the ground — closer than geosynchronous satellites orbiting our planet.

The Russian meteorite fall was significant in a scientific sense because it was a large object that exploded in an airburst, and, in a humanitarian sense, it was a tragedy because about 1,500 people were injured. They were not struck by meteorite fragments directly, but injured by shattering glass and other debris from buildings. As the meteoroid zoomed into the atmosphere over the southern Urals and exploded over the city of Chelyabinsk, it created a superheated column of air followed by a heated shock wave that knocked out windows and collapsed building walls.

This case of injuries on Earth from an impacting solar system body is almost unprecedented. Rumors abound over injuries from early meteorite falls — a Milanese friar, a German boy; a dog was even supposedly hit and "vaporized" by the Nakhla martian meteorite in 1911. The only meteorite known to have hit a person is Sylacauga, which fell in the Alabama town of that name November 30, 1954. But the Russian fall of 2013 is far beyond anything ever known before — hundreds of people injured by the effects of a small solar system body.

The Chelyabinsk fall alerts us again to the dangers posed by NEOs. The dramatic fireball was captured on many videos due to the abundance of car dashboard cameras in the region. Workplace videos showed the shock wave striking and sending employees into temporary panics. A zinc factory was apparently significantly damaged not just by the sonic wave but by impact. As many as 3,000 buildings across six cities may have been damaged.

And all this occurred because a meteoroid with a diameter presumably of only 55 feet (17m) slammed into the atmosphere at a velocity of about 11 miles per second (18 km/s) and produced an air burst some 12–15 miles (19–25km) above ground. The result? The explosive force of 500 kilotons of TNT, about 30 times more powerful than the Hiroshima bomb.

Chuck Braasch. WILLIAM ZUBACK

In other news, with our sister title, *Discover,* moving into offices in Wisconsin, just across the building from us, we lost a talented designer, Alison Mackey, who went to work on the general science title. The vacancy on *Astronomy* allowed us to welcome back an old friend, Chuck Braasch, who had worked on the title previously for six years. The *Astronomy* staff is delighted to have Braasch back, and you'll see his contributions in future issues of the magazine beginning with this one.

Yours truly,

David J. Eicher
Editor

Astronomy

Editor David J. Eicher
Art Director LuAnn Williams Belter

EDITORIAL STAFF
Managing Editor Ronald Kovach
Senior Editors Michael E. Bakich, Richard Talcott
Associate Editors Liz Kruesi, Sarah Scoles
Assistant Editor Karri Ferron
Editorial Associate Valerie Penton

ART STAFF
Senior Graphic Designer Chuck Braasch
Illustrator Roen Kelly
Production Coordinator Jodi Jeranek

CONTRIBUTING EDITORS
Bob Berman, Glenn F. Chaple, Jr., Martin George, Tony Hallas, Phil Harrington, Ray Jayawardhana, David H. Levy, Alister Ling, Steve Nadis, Stephen James O'Meara, Tom Polakis, Martin Ratcliffe, Mike D. Reynolds, Sheldon Reynolds, John Shibley, Raymond Shubinski

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Anne L. Kinney, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Publishing Co.
President Charles R. Croft
Vice President, Editorial, Publisher Kevin P. Keefe
Vice President, Advertising Scott Stollberg
Vice President, Marketing Daniel R. Lance
Corporate Art Director Maureen M. Schimmel
Managing Art Director Michael Soliday
Production Manager Helene Tsigistras
Corporate Circulation Director Michael Barbee
Group Circulation Manager Ken Meisinger
Single Copy Sales Director Jerry Burstein
Circulation Specialist Sarah Zemplinski

ADVERTISING DEPARTMENT
(888) 558-1544
Advertising Director Scott Bong
Advertising Sales Manager Jeff Felbab
Advertising Sales Representative
Ken Kozerski, kkozerski@kalmbach.com
Ad Services Representative
Christa Burbank, ads@astronomy.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544, Press 3
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (800) 533-6644; **Fax** (262) 796-1615
customerservice@kalmbach.com

SPECIAL EMAIL ADDRESSES
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com

Editorial phone: (262) 796-8776; advertising: (888) 558-1544; customer service & sales: (800) 533-6644; outside the U.S. and Canada: (262) 796-8776, ext. 421, Monday through Friday, 8:30 A.M. to 4:30 P.M. CT, Fax: (262) 796-1615; Email: customerservice@kalmbach.com. Please include your name, mailing address, and telephone number with any correspondence.

Printed in the U.S.A. Allow 6 to 8 weeks for new subscriptions and address changes. Subscription rate: single copy: $5.95; 1 year $42.95, 2 years (24 Issues) $79.95, 3 years (36 Issues) $114.95; Canadian price: 1 year $50.95, 2 years $95.95, 3 years $138.95 (Canadian price includes additional postage and GST, payable in U.S. funds.) International price: 1 year $58.95, 2 years $111.95, 3 years $162.95 (International price includes additional postage, payable in U.S. funds.) Expedited Delivery Service Surcharges: Domestic 1st Class $30 per year, Canadian air $30 per year, International air, $60 per year. BN 12271 3209 RT. Not responsible for unsolicited materials.

Follow *Astronomy*
www.twitter.com/AstronomyMag
www.facebook.com/AstronomyMagazine

The Audit Bureau
KALMBACH PUBLISHING CO.
Please Recycle This Magazine


CELEBRATE THE JOURNEY UP CLOSE.
Space Shuttle Atlantis Opens Summer 2013.
This summer, celebrate the journey of Space Shuttle Atlantis. The new 90,000-square-foot interactive Atlantis experience provides a unique vantage point to explore Atlantis up close. It tells the compelling story of the 30-year Space Shuttle Program — including its key role with the International Space Station and Hubble Space Telescope — and highlights the exciting future of space exploration. Join Atlantis on a journey of discovery unlike any other.
Explore more at TourKSC.com or call 877.634.0704.
Kennedy Space Center
VISITOR COMPLEX
OPEN DAILY
EAST OF ORLANDO


Get *Astronomy* magazine in
DIGITAL!
Powered by Zino, digital editions are available on multiple platforms: Android; iPad and iPhone; Windows 7 and 8; Blackberry; and Web OS.
HIGGS BOSON: Why you should care
Astronomy
SPECIAL ISSUE
UNDERSTANDING PLANET EARTH
How the solar system came to be
When Earth felt cosmic rain
Did life change Earth's geology?
PLUS!
Observe the Leonid meteor shower
Visiting Britain's legendary Patrick Moore
Bob Berman on the infinite universe
LIVE LINKS:
Link to website content, blogs, videos, audio, and advertisers' websites instantly
SEARCHABILITY:
Quickly search content by keyword, topic, and more
ZOOM:
Zoom in and magnify to see all the details of *Astronomy*'s stunning imagery
CONVENIENCE:
Save on storage space and view your issues wherever you are
Subscribe today at www.Astronomy.com/digitalmag
P19196

QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

PROTOPLANETS
For the first time, scientists spied streams of gas flowing across a dusty disk surrounding a young star (HD 142527) — likely feeding forming planets.

ASTEROID HUNT
Deep Space Industries announced January 22 its plan to locate, explore, and harvest asteroids. It hopes to launch the first of many "FireFlies" in 2015.

QUASAR CROWD
Astronomers discovered the largest structure as yet known in the universe: a group of active galactic nuclei called quasars that spans 4 billion light-years.

SNAPSHOT

Science's random moments

Big discoveries have come at small, seemingly insignificant times.

Science no longer works by "eureka" moments. Researchers rarely make incredible breakthroughs by themselves. Now, it's more a story of huge collaborations working on projects in tandem. But many discoveries of the past have come from seemingly insignificant moments that later changed the world. None is larger than the one that happened on an evening in the fall of 1609 in Padua, Italy.

Galileo Galilei used his newly invented telescope to gaze carefully at the steeple of a nearby church. He then, almost as an afterthought, moved over to the Moon and, in the process, revolutionized science. By making the first telescopic observation of a celestial body, Galileo noticed craters, bright and dark markings, and other "imperfections" on the Moon's surface. This was the first stroke of modern science, and it came in a small moment in northern Italy. — **David J. Eicher**

The Moon offers telescopic sights for us today just as it did for Galileo centuries ago.

NATHAN MATTHEWS (MOON); ALMA (ESO/NAOJ/NRAO)/S. CASASSUS, ET AL. (PROTOPLANETS); DEEP SPACE INDUSTRIES (ASTEROID HUNT); NASA/ESA (QUASAR CROWD)

BREAK THROUGH

Orion firing range

The outskirts of the Orion Nebula (M42) resolve into colorful pillars in this false-color photo taken in December 2012. Fine details emerge thanks to a new adaptive-optics system on the 8.1-meter Gemini South Telescope on Cerro Pachón in Chile. The system uses five laser guide stars and three deformable mirrors to sample atmospheric distortions and cancel them out in real time. The blue spots in the image are clouds of ionized iron shot from a star-forming region just outside the field of view. Traveling at supersonic speeds, these "bullets" heat the surrounding molecular hydrogen to create the orange-colored pillars. GEMINI OBSERVATORY/AURA

STRANGE**UNIVERSE**

BY BOB BERMAN

Hubble and the light-year

Why we should stick to more understandable distances.

How can we grasp the enormity of space? One thing is sure: We should at least make our units of measurement as intuitive and friendly as possible.

We often fail. Take, for example, cosmic expansion, the Hubble constant. In October, the highly respected Carnegie Observatories determined that its value is 74.3 ± 2.1 kilometers per second per megaparsec. The science media reported this verbatim.

But that doesn't help us understand what's going on. The problem is twofold. Many of us think in miles, not kilometers, and the megaparsec is even less meaningful. Have you ever heard anyone say it, even on TV? It would be easy to translate that key constant into audience-friendly language, but, strangely enough, no one does so.

Let's start by seeing why the parsec has become the professional astronomer's favorite distance unit. Bear with me: This isn't pleasant for math-o-phobes.

Earth's yearly path around the Sun makes nearby stars appear to shift back and forth against the starry background. We can determine distance by carefully measuring such vacillations; this is trigonometric parallax. Stars shift less than a second of arc, a tiny angle equal to the width of a U.S. quarter seen from 3 miles (5km) away. Turns out, we'd see a parallax shift of *exactly* 1 arcsecond if a star were 3.26 light-years away. That distance was named the parsec, an abbreviation for "PARallax of one SECond of arc." It has a cool high-tech ring we science geeks like.

Astronomers can derive a star's distance in parsecs by measuring its annual parallax and dividing it into 1. For example, Vega's parallax is 0.13 arcsecond, which divided into 1 yields a distance of 7.69 parsecs. So the parsec is a logical unit in the field of astrometrics, which is able to directly measure the 118,000 nearest stars.

Past a few thousand light-years, however, parallaxes get too small. So this distance-finding method works for fewer than one in a million of our galaxy's stars and for none of the 125 billion known galaxies. For virtually the entire universe, you have to find distance by another method and then express it using whatever unit you wish — parsecs, light-years, furlongs, it doesn't matter. Parsec offers no advantage.

Astronomers attach prefixes like *kilo-* and *mega-* to the word to talk about objects thousands or millions of parsecs away. Thus, we've now arrived at that *megaparsec* term, invariably used when citing the Hubble constant.

Here's why *light-year* and *million light-years* are superior. Unlike with the parsec, there are no angular measurements involved and no math derivations. Light is familiar and fast. A photon could make almost 72 trips from Boston to Hollywood in a single second. Even at that speed, light takes roughly an hour to get here from Saturn. Thus, Saturn is about 1 light-hour from us. Simple. Light's travel-distance in a year is, of course, a light-year. It's huge and yet intuitive. That its speed never varies in the emptiness of space is icing on the cake and provides a valuable, rare commodity: a *constant*.

The nearest spiral galaxy, Andromeda, lies 2.5 million light-years away. We can make sense of this several different ways. We might note that when we observe Andromeda, its light began its journey 2.5 million years ago, just as early hominids were learning to stand upright when eating their sushi. Or we could say that if our technology ever creates rockets that can zoom at nearly light speed (today's best are 18,000 times slower), we could reach Andromeda after 2.5 million years of travel. Either way, the true enormity of its distance hits home.

All such musings spring to mind simply by hearing the galaxy's remoteness expressed in light-years. No analogies or appreciations pop up if we instead cite its distance as 767 kiloparsecs.

Light has gifted the human mind with an easy unit for expressing large distances. Let's now use it for the Hubble constant. According to the newest data, the universe's rate of expansion is 14 miles per second faster for each million light-years of distance. Thus, a galaxy 100 million light-years away zooms 1,400 miles a second.

Think of a city 1,400 miles from you. Visualize going there in one second. That's the speed a galaxy races away if it happens to lie 100 million light-years from us. Voilà, you've grasped the cosmic expansion rate. (If you prefer metric, the Hubble constant is 23 kilometers per second per million light-years.)

Now try using 74 kilometers per megaparsec. Nothing clicks.

I probably sound like a lunatic on a soapbox, cursing the parsec and cooing with unholy adoration for the light-year. I don't care. We should always use light-years for stuff like this. It's just too sensible to abandon.

Join the crusade. Save the light-year.

HAVE YOU EVER HEARD ANYONE SAY "MEGAPARSEC," EVEN ON TV?

Contact me about my strange universe by visiting **http://skymanbob.com.**

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

QUANTUM GRAVITY

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Sarah Scoles**

Cold as space — Supernova hot

What a drag

A *British Medical Journal* paper asks, "How healthy should space tourists be?" A better question is, "When will space shops sell 'I went to space, and all I got were these squished eyeballs' T-shirts?"

Food group

The USDA will soon recommend filling your plate with the new "green bean galaxies" in addition to the already known "green pea galaxies" and Bok (choy) globules to meet veggie requirements.

Representative democracy

A petition to begin construction on a "Death Star" by 2016 receives 25,000 signatures, the number required for an official White House response. The Force is strong with this one.

Ear worm

NASA interns make a video called "NASA Johnson Style," a parody of "Gangnam Style." Star Eric Sim shows the world how space center employees do it: outside rockets, with astronauts.

NASA (WHAT A DRAG); CFHT/ESO/M. SCHIRMER (FOOD GROUP); COMSTOCK/THINKSTOCK (REPRESENTATIVE DEMOCRACY); NASA (EAR WORM)

 MIRROR, MIRROR. The James Webb Space Telescope's last optical subsystem is complete and ready for integration, NASA announced January 16. This component feeds photons from the secondary mirror to the recording instruments.

STAR BIRTH. Newly discovered regions of ionized hydrogen (red) trace massive-star formation in the Milky Way and provide clues about our galaxy's history and evolution. RADIO: HRDS SURVEY TEAM/NRAO/AUI/NSF; OPTICAL: AXEL MELLINGER

MASSIVE STAR-FORMING REGIONS ILLUMINATE GALACTIC HISTORY

Astronomers have found hundreds of previously unknown massive-star nurseries in the Milky Way, they reported January 10 at the American Astronomical Society meeting in Long Beach, California. The star-forming areas, called ionized hydrogen (HII) regions, trace the galaxy's arms and central bar.

Scientists used the National Radio Astronomy Observatory's Green Bank Telescope (GBT) to search the galaxy for the specific radio-wave frequency that HII atoms emit. This GBT survey more than doubled the number of known massive-star birthplaces, and the researchers then used the Arecibo Observatory to find even more, including one 300 light-years wide.

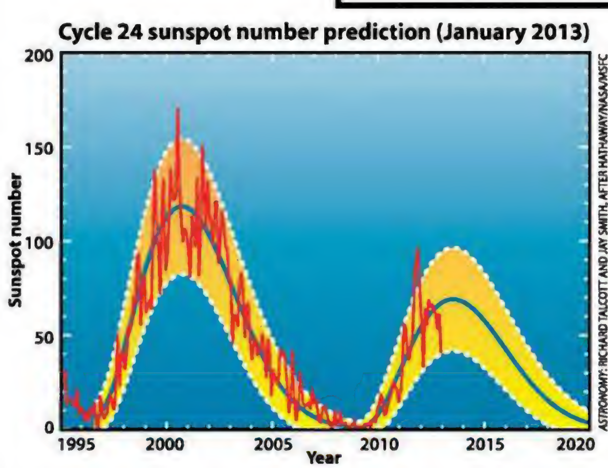
The astronomers continued to uncover stellar birthplaces by training the radio telescopes on locations that NASA's Spitzer and Widefield Infrared Survey Explorer telescopes had identified as infrared hot spots.

After the team finds a new HII region, they search for fainter emissions from heavier elements, like helium and carbon, which provide clues about the Milky Way's compositional and structural evolution.

"We're working to improve the map of our galaxy to advance our understanding of its structure and its history," says research team member Thomas Bania of Boston University. "The radio telescopes are our tools for making these new and better maps." — **Sarah Scoles**

SOLAR ACTIVITY ON THE RISE

FAST FACT The solar cycle currently averages about 11 years from peak to peak and has been proceeding uninterrupted since the early 18th century.



SOLAR MAX. Solar cycle 24 is shaping up to be the weakest in a century. Scientists at NASA's Marshall Space Flight Center in Huntsville, Alabama, updated their prediction in January and now anticipate the cycle will peak this autumn. The number of sunspots (officially the smoothed International Sunspot Number) should reach about 69, a drop of some 40 percent from the 2000 peak. That would make this the lowest maximum since cycle 14 peaked at 64 in February 1906. (The colored band shows the expected range of the monthly sunspot numbers.)

BRIEFCASE

STARS ENERGIZE "FERMI BUBBLES"

Astronomers report in the January 3 issue of *Nature* the discovery of giant radio bubbles at the Milky Way's center. These correspond to the huge structures (dubbed "Fermi bubbles") discovered a couple of years ago in gamma rays and microwaves. The researchers say the radio waves are polarized — meaning they have a specific orientation — which indicates magnetic fields are present in the structures. They studied these magnetic fields to determine that many generations of star birth and death create the huge bubbles. — **Liz Kruesi**

TITAN MIGHT HAVE SURFACE ICE

NASA's Cassini spacecraft has determined that lakes of hydrocarbons (like ethane and methane) cover the surface of Saturn's moon Titan. The solid forms of both ethane and methane are denser than their liquid forms and thus would sink. However, a mixture of the solid states of these molecules might instead float, according to a study that will appear in a future issue of *Icarus*. — **L. K.**

CLOUDY, WITH NO CHANCE OF STARS

Using millimeter-wave detectors, a team of astronomers has measured the density of a cloud of gas that should contain forming stars but does not. Its density is some 45 times that expected to initiate star formation, the team will report in a future issue of *The Astrophysical Journal Letters*. This cloud, G0.253+0.016, is part of a larger ring structure in the galaxy's core. — **L. K.**

25 years ago in *Astronomy*

In May 1988, *Astronomy* reported the results of a poll about space exploration. The magazine asked readers what they would like to see as NASA's dominant focus. "Manned spaceflight" was the top answer, getting 32 percent of the vote, but "solar system exploration" ran a close second.

Respondents were concerned about the Soviet Union's "apparent lead over the United States," but most agreed, as Jim Egger of Palmer, Alaska, said, "We need to learn to seek knowledge because of the rewards of having that knowledge, not just to beat someone else."

10 years ago in *Astronomy*

The May 2003 issue featured William Schomaker's article entitled "Big glass," which showcased five state-of-the-art optical instruments: the Hobby-Eberly, Subaru, and Very Large telescopes and Keck and Gemini observatories.

The telescopes "testify to the technological innovation and cyber sophistication at the turn of the century," Schomaker said. "With the combined light-gathering power of a million pairs of human eyes each, they rival the performance of the best space observatories." The telescopes continue to produce cutting-edge scientific results. — **S. S.**

FAST FACT

The Andromeda Galaxy contains more than 300 billion stars whose total mass may exceed 1 trillion Suns.

STRUCTURED SATELLITES. Astronomers have discovered that 13 satellite galaxies orbit the larger Andromeda Galaxy in a plane. Current models do not predict such an orderly structure. J.-C. CUILLANDRE (CFHT)/G. ANSELMI (COELUM)

Andromeda satellites surprise astronomers

Current theories of galaxy formation and evolution include the idea that dwarf satellite galaxies should randomly orbit their large brethren. So when astronomers with the Pan-Andromeda Archaeological Survey (PAndAS) began collecting data for the first panoramic view of the Andromeda Galaxy, they expected observations to match the models. Their results, however, as published in the January 3 issue of *Nature*, show a much more orderly structure.

Of the 27 dwarf galaxies the scientists studied, 13 move uniformly in a plane around Andromeda, analogous to how the major planets in our solar system orbit the Sun. The planar structure is about 1 million light-years across but only 46,000 light-years thick. Although previous studies hinted at such a configuration, the PAndAS team has demonstrated its existence to 99.998 percent confidence. Current data suggest a similar structure of dwarf galaxies exists around the Milky Way.

The authors of the paper hypothesize possible reasons for such a structure, but they conclude that it remains to be seen whether current models can explain such an orderly configuration. "We don't yet know where this is pointing us," says lead author Rodrigo Ibata of the Strasbourg Astronomical Observatory in France. "It flies in the face of our ideas about galaxy formation, but it surely is very exciting." — **Karri Ferron**

QUICK TAKES

MARSHY MARS
A 2.1-billion-year-old martian meteorite has 10 times more water than other rocks from Mars, implying a formerly wet planet, reports a paper in the January 3 *Science* Express.

•

CESIUM CUCKOO
Scientists in the February 1 issue of *Science* describe a new kind of atomic clock that measures time by counting cesium atoms' oscillations, which depend on their masses.

•

IO DID WHAT?
A paper to appear in a future issue of *Geophysical Research Letters* shows that Io's volcanoes change Jupiter's magnetosphere and decrease aurorae.

•

PLENTIFUL PLANETS
Planet Hunters citizen scientists discovered 15 habitable-zone candidates, the program announced January 7.

•

DUSTY DWARFS
The Hyades' white dwarfs have heavy elements from ground-up asteroids, according to a January 8 talk at the American Astronomical Society meeting in Long Beach, California.

•

DARK ARTS
NASA announced January 24 that it will join the European Space Agency's Euclid mission to investigate dark matter and dark energy.

•

BLACK HOLE BMI
A *Nature* paper published online January 30 says the dynamics of gas around black holes reveal the mysterious objects' masses. — **S. S.**

Meteoroid disintegrates over Russia

At about 9:20 A.M. local time February 15, a space rock some 55 feet (17 meters) in diameter entered Earth's atmosphere and erupted over the Urals region in Russia. The "tiny asteroid," as Paul Chodas of the Near-Earth Object Program Office at NASA's Jet Propulsion Laboratory referred to it, weighed about 10,000 tons and penetrated the atmosphere at some 40,000 mph (18 kilometers per second).

The meteoroid broke up between 12 and 15 miles (19 and 24 km) above Earth's surface. The resulting airburst released 500 kilotons of air pressure in a shock wave that quickly reached the ground. The blast damaged buildings, shattered windows, and injured as many as 1,500 people. This was the largest such impact since the Tunguska event over Siberia in 1908. — **K. F.**

RIA NOVOSTI/SCIENCE SOURCE

FORCEFUL FIREBALL. A 10,000-ton meteoroid broke up above Chelyabinsk, Russia, on February 15, creating a shock wave that caused serious damage to the region.

BY GLENN CHAPLE

Close encounters

Careful observation is key to avoiding the unidentified.

Have you ever seen a UFO? I have — twice. Well, kind of, at first.

My first "close encounter" occurred in March 1970 as I stood in a field at sunset. Facing west, I scanned the horizon for a glimpse of the elusive planet Mercury. I spotted a light, but it was much too bright to be Mercury. It couldn't be Venus, which was a morning planet at the time. Besides, this light was moving silently and steadily toward me. Suddenly, it made an abrupt 90° turn and disappeared. I was astounded. No earthly craft could have conducted such a maneuver!

Close encounter number two took place at an evening outdoor concert about 20 summers ago. As I gazed upward at the evening sky (something *all* amateur astronomers do at evening outdoor concerts), I noticed a formation of lights looming above the treetops and edging closer. They were lined up parallel to the horizon and moving from side to side. The unearthly sight conjured up an image of concertgoers fleeing in panic as death rays rained down from an invading armada of alien craft.

Each of these episodes is what ufologists refer to as a "close encounter of the first kind" — a visual sighting of a UFO. As exciting as mine were, they quickly became IFOs (identified flying objects).

In the first instance, I opted to remain in the field rather than rush indoors to describe the incident to my wife. It wasn't long before my ears picked up the far-off drone of an airplane engine. As the plane neared, I noticed a flash of sunlight reflecting off its fuselage. My UFO must have been a similar reflection off one of the aircraft's wingtips. The plane might have made a banking maneuver, causing the reflection to race across the wings at a 90° angle to the plane's motion.

The would-be alien invasion at the outdoor concert was also airplane-produced. As I tensed to make a mad dash for the exit, I heard the unmistakable sound of an approaching airplane. Mounted underneath was a lighting system similar to the lit-up message boards that blimps carry at nighttime sporting events. A fleet of marauding spacecraft turned out to be nothing more than an advertisement for a local radio station.

Those two episodes were the closest I've ever gotten to making a bona fide UFO sighting. Despite thousands of hours of backyard astronomy, not to mention thousands more on camping trips and nighttime strolls, my lifetime UFO count is zip, zilch, zero! I suspect the same holds true for most experienced amateur astronomers.

Truth be told, amateur astronomers are lousy UFO reporters. We know the night sky too well to be fooled by after-dark sights such as planetary apparitions, brilliant meteors, International Space Station flyovers, Iridium flares, and other events that confuse and alarm the general public. We see Venus; John and Jane Doe see a hovering UFO.

Outside at the telescope a number of years ago, I looked up to see a luminous patch of light high in the southern sky. Circular and multicolored, it slowly expanded and faded from view. I guessed that it was some sort of high-altitude scientific experiment and calmly returned to the telescope. At the same time, throngs of East Coast residents were rushing to their phones to call their local newspapers or police in a frantic effort to find out what was invading our skies. There was no need to panic. The spectral sight was indeed terrestrial in origin. A suborbital rocket fired from NASA's Wallops Flight Facility in Virginia had released a barium cloud into the ionosphere to study the dynamics of the upper atmosphere.

A number of recent UFO sightings have described mysterious formations of yellow lights that bob up and down in the twilight or evening sky. If you've ever been at an evening wedding or holiday celebration, you know their nature. The bobbing yellow lights are Chinese lanterns — small paper "hot air balloons" carried aloft and illuminated by small candles suspended beneath them.

If I've piqued your interest in UFOs, check out "Bad Astronomer" Philip Plait's article "The science behind UFOs" (p. 44). Plait relates his own UFO experience and then describes and explains several notable "extraterrestrial" sightings.

The next time you see something unidentifiable in the night sky, go through the usual list of possibilities — planet, aircraft, satellite, weather balloon, and so on. If none of them work, wait and *observe*. Just do it from a concealed location — you never know!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Seeing double (stars)! Clear skies!

An Iridium flare, like the one pictured on the right side of this long-exposure image, is just one night-sky occurrence that confuses the general public. MIGUEL CLARO

FROM OUR INBOX

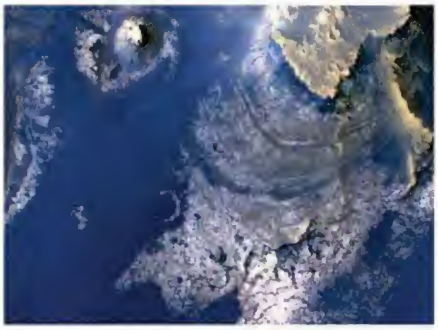
An altered design, and a correction

All in all, your magazine redesign, introduced in the January 2013 issue, is a great success. The "Quantum Gravity" section is a welcome change but with one problem — text readability. The font size is so small for some of the articles that it was a strain to read them. I realize that you have a difficult tradeoff between quantity of content and readability, but I believe that you decreased text size too much. Otherwise, congratulations on a fine upgrade of your already superior magazine. — **Bill Haney,** Melfa, Virginia

The Sharpless objects pictured at the top of page 72 in the February issue should have been labeled Sh 2–268, Sh 2–269, Sh 2–270, Sh 2–271, and Sh 2–272. — ***Astronomy* Editors**

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/Chaple.**

LIGHT BRIGHT. Five "hot spots" around the black hole at the center of NGC 660 burn 10 times brighter than the brightest supernova, astronomers reported January 7 at the American Astronomical Society meeting in Long Beach, California.



EXTRATERRESTRIAL ECOLOGY. The High Resolution Imaging Science Experiment camera on NASA's Mars Reconnaissance Orbiter recorded this picture of McLaughlin Crater, where rocks appear to have been wet in the past. NASA/JPL-CALTECH/UNIV. OF ARIZONA

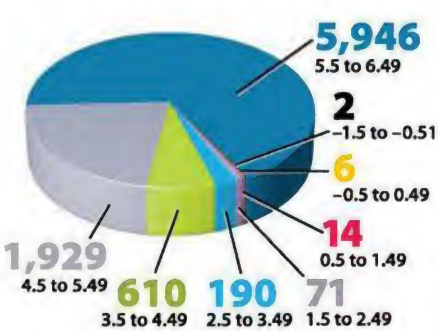
Minerals suggest groundwater-fed lake once existed on Mars

While looking down at Mars' 1.4-mile-deep (2.3 kilometers) McLaughlin Crater, NASA's Mars Reconnaissance Orbiter saw evidence that the geologic bowl once held water, a paper published online January 20 in *Nature Geoscience* reports.

Sedimentary rocks at the bottom of the crater contain carbonate and clay minerals that form when water is around. Scientists speculate that because McLaughlin is so deep, water that flowed underground on more elevated parts of the planet popped above the surface when it came to this depression, just as it does in similar geography on Earth. Small channels in the crater wall suggest the groundwater flowed into a full-fledged martian lake that potentially harbored life in the past.

"This new report and others are continuing to reveal a more complex Mars than previously appreciated, with at least some areas more likely to reveal signs of ancient life than others," says project scientist Rich Zurek of NASA's Jet Propulsion Laboratory in Pasadena, California. — **S. S.**

HOW MANY STARS ARE THAT BRIGHT?



IT'S FULL OF STARS. This chart shows the numbers of stars in each magnitude range. A range defines each magnitude. For example, any star whose brightness lies between magnitude 1.5 and magnitude 2.49 is a 2nd-magnitude star. *ASTRONOMY*: MICHAEL E. BAKICH AND ROEN KELLY

SPACE SCIENCE UPDATE

PLANETS ARE ALL THE RAGE

The 221st meeting of the American Astronomical Society (AAS) in Long Beach, California, was host to a wave of news about the search for worlds outside our solar system.

The main workhorse in the hunt is NASA's Kepler spacecraft, which has been staring at more than 150,000 stars for nearly four years to monitor their brightnesses. A change in luminosity could mean that a planet orbiting one of those stars passed between its sun and us, thus blocking light in what's called a transit. But it could also mean a flare erupted from the star's surface or that the sun is a member of a binary star system. Scientists need at least three dimmings to consider such an event a possible planet. They narrow down how many brightness variations are likely due to orbiting exoplanets, and then they observe those stars with additional telescopes.

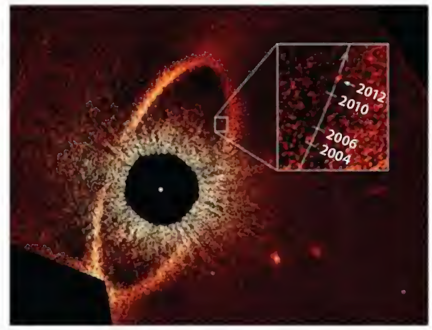
On January 7, the Kepler team announced that they had sifted through 13,000 transit-like signals and found another 461 candidate planets in the spacecraft's observations, to bring the total to 2,740. Christopher Burke of NASA explained that most of the new possible planets are Earth-sized or super-Earth-sized. Scientists also are finding more multiple-planet systems as the mission continues because they can now detect candidate worlds that are in orbits similar to Earth's.

So far, researchers have confirmed 105 Kepler planets and found that about 10 to 15 percent of the candidate worlds end up being false positives. John Johnson of Caltech explained that scientists usually can rule out false positives by just looking at light curves, which is a "testament to the quality of Kepler."

During the same press conference, Francois Fressin of the Harvard-Smithsonian Center for Astrophysics described how he and colleagues used Kepler statistics to determine that 17 percent of stars have an Earth-sized planet within Mercury's orbit. Kepler sees only planets that transit their stars from our point of view, so there are many worlds that it won't detect. Fressin's team incorporated this information and the percentage of false positives from Kepler data in its analysis.

Other findings detailed at the AAS meeting focused on observing dusty disks surrounding young stars; these are prime locations for forming planets. Joseph Carson of the College of Charleston described his team's direct imaging of a debris disk around a star about twice the Sun's mass, called HIP 79977. The disk extends some 10 times farther out than the Kuiper Belt does, and it contains much more material. Carson's team also found a pointlike source within the disk after subtracting out the star's and disk's light; it may be a planet or a clump of disk material.

Another team reported at AAS that the star Fomalhaut does have an orbiting planet traveling through a dust belt. (Scientists have argued over the past few years whether this world actually exists.) The astronomers compared images of the system taken in 2004, 2006, 2010, and 2012 to confirm a planet with a highly elliptical 2,000-year orbit. — **L. K.**



NASA/ESA/P. KALAS (UC BERKELEY/SETI INSTITUTE)

GOING ROGUE. With observations spanning eight years, scientists can now calculate the highly elliptical orbit of Fomalhaut b. This planet takes some 2,000 years to travel around its star, and that path brings it through the planetary system's dusty belt.

X-RAY: NASA/JPL; OPTICAL: CALTECH/DSS

Bright black holes

CURIOUSLY STRONG. Seven million light-years away is galaxy IC 342, a spiral with puzzlingly energetic black holes. When NASA's Nuclear Spectroscopic Telescope Array observed this galaxy, it saw two ultraluminous X-ray sources (ULXs). They are 10 times brighter than stellar-mass black holes but not centrally located enough to be associated with IC 342's supermassive black hole. Scientists suspect they may be mysterious intermediate-mass black holes or stellar-mass objects undergoing an unknown, energetic process. In this image released January 7, the X-ray data (magenta) are superimposed over an optical image of the galaxy, showing the ULXs' spiral-arm homes. — **S. S.**

FAST FACT

NGC 6872's record-breaking size results from an interaction with dwarf galaxy IC 4970 at its northern arm. The pair lies about 212 million light-years from Earth.


NASA'S GODDARD SPACE FLIGHT CENTER/ESO/JPL-CALTECH/DSS

Record galaxy

LONG LIMBS. NGC 6872 has earned the title of the largest spiral galaxy known. The distance between the tips of its two outstretched arms is some 522,000 light-years — that's more than four times the Milky Way's size. Astronomers used the Galaxy Evolution Explorer mission to capture NGC 6872's ultraviolet radiation, which indicates the formation of hot stars. The youngest stars appear in the far end of the northwestern arm. This ultraviolet, visible, and infrared composite was released January 10. **— L. K.**

COMING IN OUR NEXT ISSUE

HOW TO FIND ET WITH INFRARED LIGHT

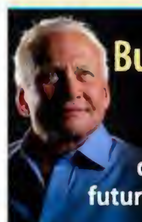
The search for extraterrestrial intelligence has mostly revolved around radio signal detection, but such a civilization's heat signature also could give away its location

NASA/STEREO

Russia's big bang

A look back at the February 15 meteorite and the threat of similar near-Earth objects

Astronomy: Roen Kelly



Buzz Aldrin on our future in space

The former astronaut depicts the legacy and future of space exploration

Courtesy of Buzz Aldrin

PLUS

- Explore the ultimate planetary nebula catalog
- Nicolas de Lacaille: Bringing order to the southern skies
- What are we learning from Moon rocks?
- Discover our solar system's hidden wonders
- All about Bushnell's 5-inch reflector

Astronomy magazine

ASTRO**CONFIDENTIAL** BY KARRI FERRON

WHAT ARE WE LEARNING FROM THE DISCOVERY OF "GREEN BEAN GALAXIES"?

Mischa Schirmer Science fellow at Gemini Observatory South in Chile

One of the major discoveries in galaxy evolution is that most massive galaxies each harbor a supermassive black hole a million to a billion times heavier than the Sun. These black holes grow by swallowing stars and gas from their surroundings, a process that releases large amounts of energy. X-rays ionize the interstellar gas within a few hundred to a few thousand light-years of the nucleus, and well beyond that in a few very active systems (called quasars). Scientists believe that these active growth phases last about 100 million years. Depending on the continuous supply of material, the luminosity of such a quasar may change by 10 percent over a few hours up to a factor of 10 over a decade. The onset or complete shutdown of a quasar is expected to last well over 100,000 years and has thus never been observed directly.

In the gas-rich "green bean galaxies" my team recently discovered (named for their unusal color and appearance), the interstellar material is ionized throughout. The luminosities of double-ionized oxygen are among the highest ever observed, which can only be explained by very active quasars. However, further observations have revealed that the activity of the black holes appears five to 50 times less than expected. We can only explain this if the black hole has indeed recently reduced its activity significantly. The glowing gas in the galaxy thus represents an earlier, much more active state, still ionized by the older X-ray photons while they propagate through the galaxy.

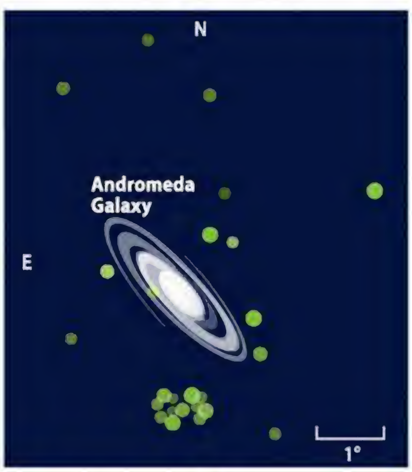
These so-called ionization echoes enable us to observe by how much a quasar can change its brightness over about 100,000 years and therefore test our theoretical understanding of the life of active galaxies. However, before we can embark on this endeavor, we need more data from the largest telescopes to better understand the characteristics of these enigmatic galaxies.

KARIANNE HOLHJEM

ASTRO**NEWS**

BOOM BOOM POW. According to a paper published online January 21 by the *Monthly Notices of the Royal Astronomical Society*, a gamma-ray burst likely led to the radioactive isotopes found in tree rings from A.D. 775.

HASTY, HULKING HYDROGEN



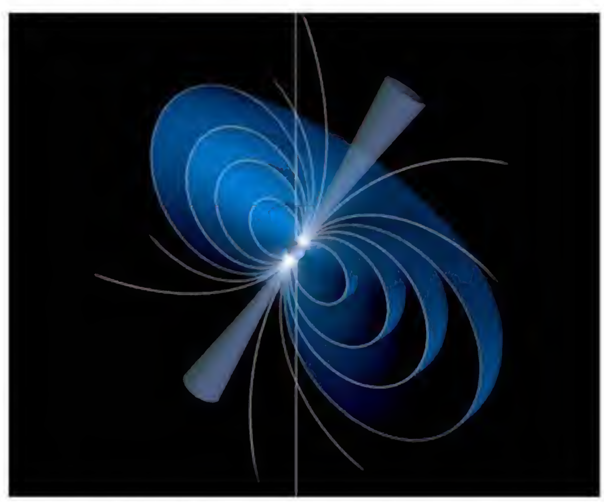
FAST GAS. Clouds of neutral hydrogen (HI) gas fly toward the Andromeda Galaxy (M31) at speeds sometimes double the galaxy's rotation rate. These high-velocity clouds (HVCs) are remnants of galactic birth and cluster interactions and provide fuel for future star formation. The plot above shows the locations and masses of the HVCs around M31. They range from 200,000 times to 6 million times the mass of the Sun and travel 111–319 miles per second (179–514 km/s). *ASTRONOMY*: SARAH SCOLES AND ROEN KELLY

Pulsars flip-flop their radio waves and X-rays

Pulsars, the spinning neutron stars that emit beams of radiation in Earth's direction once per rotation, can change the brightness of their radio waves and X-rays suddenly and simultaneously. When radio waves become bright, however, X-rays go dim, according to results reported in the January 25 issue of *Science*. Astronomers' current understanding of pulsars cannot explain this switch, which happens in seconds.

Although scientist Jocelyn Bell discovered these objects, which have masses similar to the Sun's but are only as big as a city, 45 years ago, astronomers still do not know exactly what causes the intense radiation that streams from their magnetic poles. While they knew that pulsars' radio patterns could flip between several states, this is the first time scientists have witnessed their X-ray variability. When researchers compared these X-ray changes to the radio changes, they saw that the two were always in opposite states but flipped at the same time.

The change takes place faster than scientists expected it could. Project leader Wim Hermsen of the Space Research Organization Netherlands says: "Most striking was that this metamorphosis takes place within seconds, after which the pulsar remains stable in its new state for a few hours. Why a pulsar should undergo such dramatic and unpredictable changes cannot be explained by current theory. It strongly suggests a quick change of the entire magnetosphere." — **S. S.**



IMPULSIVE PULSARS. Pulsars in "radio-bright" mode beam radio waves in cones from their magnetic poles. When they are emitting X-rays, the "hot spots" also shine from the poles, as they do in this image. Curiously, when the radio waves are strong, the X-rays are dim, and vice versa. ESA/ATG MEDIALAB

SECRET SKY
BY STEPHEN JAMES O'MEARA

Effects of the eclipse

In the totality of an eclipse, viewers make both scientific and personal observations.

On November 14, 2012, I watched without optical aid as the Moon covered the Sun. From the deck of Celebrity Cruise's *Millennium* in the South Pacific, the other passengers and I enjoyed 3½ minutes of eclipse totality under a cloud-free sky. Perhaps the most inspiring sight occurred just before second contact, when the Moon's edge was poised to cross in front of the Sun and began the total eclipse. Sunlight fringed the Moon's leading edge, which lingered for an inordinate amount of time in what is known as the "diamond ring effect." Then, the corona flared to prominence with diaphanous petals fully encircling the Moon's silhouette. If I used averted vision, the coronal petals tapered into fine threads of silk that tickled the surrounding indigo sky.

One of the more subtle coronal details visible to the eye was its extremely pale sea-green color. I had seen this hue before, but not so noticeably. If I relaxed my gaze and looked slightly away from the Sun, but kept my attention on the corona, totality seemed awash in green light.

Zodiacal light?

Near the end of the eclipse, with perhaps only 30 seconds to go, I once again relaxed my gaze and noticed a mottling on the Moon's dark face. While in this relaxed state, and by then being somewhat dark-adapted, my eye suddenly caught sight of a very dim strip of light that extended along the zodiac about 10°–15° — half the distance to Venus to the west and clean through Mercury to the east. Curiously, the dim glow seemed to trumpet open on either end.

The appearance of this band had none of the visual characteristics of the corona. In fact, it looked as if the eclipsed Sun with its bright, irregularly round corona was "tacked on" to this extremely faint band.

Given that the light strip followed the zodiac, I had to wonder if it was not, in fact, some rare coronal feature that extended into the zodiacal light — the milky band of dust (from comet dust and asteroid collisions) lying in the plane of the inner solar system out to about the orbit of Jupiter. I would love to hear from others who may have thoughts (or images) of this phenomenon.

Different strokes

While this feature was visible without a telescope or photographic setup, some observers surely caught it on camera. Equipment and technology have now evolved to the point where even inexpensive pocket cameras can capture images rivaling some professional ones. The shots provide users with not only the thrill of success but also stunning views they can share instantly over the Internet, satiating the thirst of followers. Over the years, I've watched people's excitement at shooting totality overshadow the viewing of it. On the opposite side of the spectrum, we have those who choose to view the eclipse but generally keep what they see close to the chest — the eclipse being for them more of a personal and a spiritual experience than a purely scientific quest.

In the future, I anticipate the photographic experience will continue to go supernova over the Web. I also foresee totality continuing to implode into the souls of individual viewers. There always will be plenty of people in both camps. There is a third group of people, though: those who are interested in scientific, naked-eye viewing. I'm uncertain about the future of such visual observations during totality. Do you think there is any value remaining to observing (not merely watching) an eclipse? Email your thoughts to someara@interpac.net

This inverse shot of totality through a 10mm fisheye lens shows an extended, diagonal glow along the ecliptic, continuing past the corona. STEPHEN JAMES O'MEARA

Although the Moon does not look as if it is covering the Sun's disk in the original image, the light actually represents the normal extent of the corona. STEPHEN JAMES O'MEARA

FROM OUR INBOX

Humans are not insignificant

While viewing the "100 Greatest Pictures of the Universe" in *Astronomy*'s October 2012 issue, I was dumbfounded by the majestic beauty and power contained within each image. While a friend of mine and I discussed the issue, he noted that the pictures showcase more than astronomical interests: They reinforce the notion of our insignificance in the universe.

I am disheartened by such commentary from some scientifically minded individuals that humanity is "insignificant" when compared to the immensity of space. I would think that those who are able to understand and appreciate humanity's complexities, its idiosyncrasies, and its cynicism would be able to contemplate our significance on one level or another, even if we, as a species, might occasionally take liberties with the matter. To quote Carl Sagan, "The cosmos is also within us. We're made of star stuff. We are a way for the cosmos to know itself." If we are the product of an infinite cosmos that can create light-years of beauty, then I cannot see how a few feet of flesh is any less important than the Pleiades. — **Blake Cunningham,** Moss Point, Mississippi

BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

WEBTALK

What's new at Astronomy.com.
BY KARRI FERRON

MOBILE UPDATES » Scan the code to access the latest news and observing info from your mobile device.

Everything you need to know about 2013's celestial visitors

A dazzling comet can ignite a viewer's passion better than almost any other celestial object. And those flames will burn bright this year as 2013 promises not one, but two bright comets to target. The first of the year, C/2011 L4 (PANSTARRS), graces the sky among the constellations Andromeda and Cassiopeia in April as it fades from its peak. Meanwhile, Comet C/2012 S1 (ISON) remains hidden in Gemini to all but the largest amateur telescopes. Its breathtaking views are predicted to come in late November as it crosses the constellation Scorpius.

To ensure readers have all the best information and can experience the beauty of these comets through great photos and videos, *Astronomy*'s editors are devoting a whole section of Astronomy.com to "The Year of the Comet." Head to **www.Astronomy.com/comet** for finder charts, images, prediction updates, observing tips, videos, and more for both comets as they make their first known visits to the inner solar system. And we want your involvement. If you have images, observing reports, planned star parties, or suggested updates to share about PANSTARRS or ISON, send them to Senior Editor Michael E. Bakich at mbakich@astronomy.com. 2013 should be a great year for amateur astronomy.

FOLLOW *ASTRONOMY* www.twitter.com/AstronomyMag www.facebook.com/AstronomyMagazine

OBSERVING TOOLS

Celestial Portraits

Astronomy's editors have compiled a series of 11 digital packages called "Celestial Portraits" for observers to purchase and download. The collection highlights all 88 constellations and explains how to observe the deep-sky targets within each one. Every package contains articles with easy-to-read star charts, tables with detailed information on deep-sky objects, beautiful photos from amateur astroimagers, constellation mythologies with portraits based on them, and more. Download a free preview of Orion the Hunter at **www.Astronomy.com/portraits**.

COMMUNITY

Reader Photo Gallery

Browse thousands of beautiful astroimages like this one of the Milky Way by Jeff Dai. Submit your own at **www.Astronomy.com/readergallery**.

Community Events

Find star parties, public outreach gatherings, or lectures in your area or post an invite to your astronomy club event at **www.Astronomy.com/events**. It's a great way to introduce people to the hobby or get to know others who share your passion about our night sky.

REGISTER TODAY! **Go to www.Astronomy.com/register for access to bonus articles, photos, videos, and more.**

HOW LIFE SURVIVED

The Sun was barely two-thirds as bright in its youth as it is today. So how did Earth's surface stay warm enough for liquid water to exist and life to emerge?

by Bruce Dorminey

More than 3.5 billion years ago, not long after our young Earth morphed from a hot molten state into a solid planet and only primitive cyanobacteria drifted in our oceans, the Sun was some 30 percent fainter than it is today. That's no surprise. Models of stellar evolution clearly show that during their hydrogen-burning main sequence lives, Sun-like stars grow steadily more luminous, adding a bit less than 10 percent to their brightness every billion years. The surprise is that in the presence of such a faint Sun, Earth would have had liquid water at all.

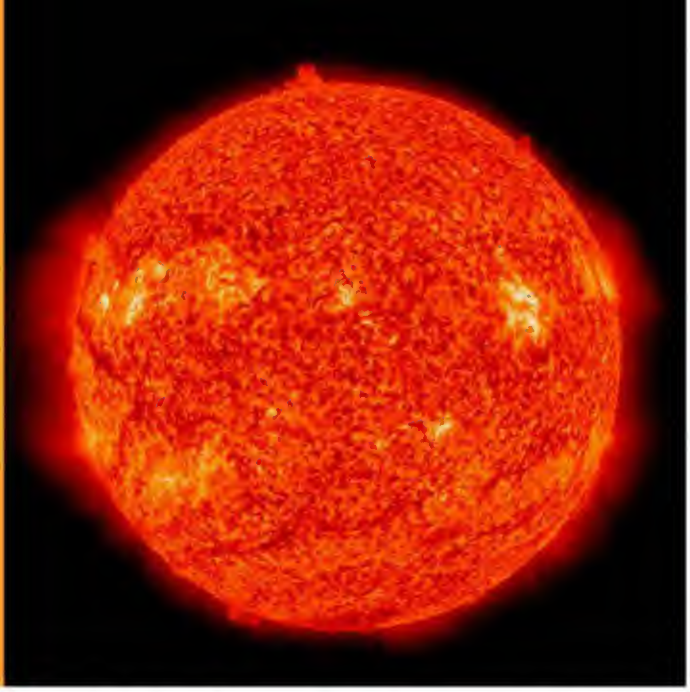
By all accounts, our planet's surface should have been frozen solid for the first 2 billion of its 4.5-billion-year history. But the geologic record from the Archean Eon, which dates from 3.8 to 2.5 billion years ago, contains more than enough evidence that liquid water and clement conditions existed at the surface — and primitive life gained a strong foothold. Some researchers estimate that Earth's oceans at this time may have had temperatures above 130° Fahrenheit (55° Celsius). That's roughly halfway to the boiling point of water under current atmospheric conditions.

Scientists have labeled this conundrum the "faint young Sun paradox." But some investigators can't even agree on the proper terminology. "It's not a paradox — that's hyperbole," says planetary scientist David Stevenson of the California Institute of Technology. "It's something less than a paradox. It's a puzzle." Whatever it is, it has plagued astrophysicists and geoscientists

Frequent contributor **Bruce Dorminey** *is a science journalist and author of* Distant Wanderers: the Search for Planets Beyond the Solar System *(Springer, 2001).*

A COOL EARLY SUN

Some 3.8 billion years ago, liquid water and primitive life existed on Earth's surface despite a Sun that radiated far less energy than it does today. RON MILLER FOR *ASTRONOMY*



The Sun is a roiling ball of hot gas, but it once was only some 70 percent as bright as it is today. NASA/SDO/AIA

Why wasn't Earth frozen solid when the Sun was much less luminous in its early days?

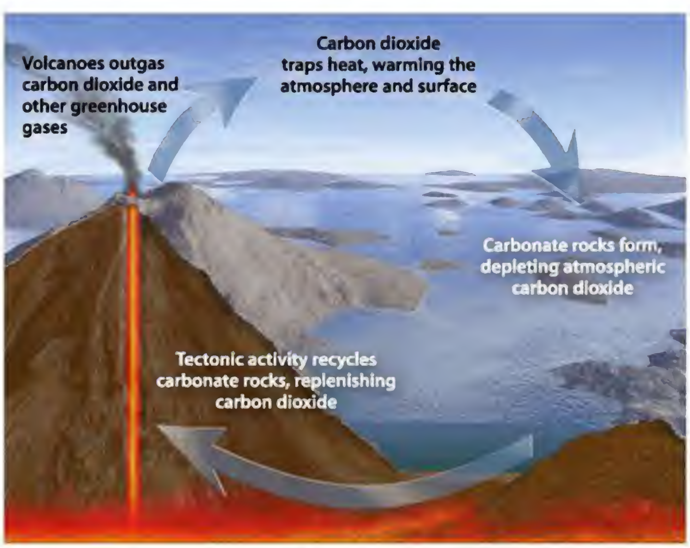
alike since 1972, when Carl Sagan and George Mullen of Cornell University first examined the problem.

In the four decades since, scientists have proposed all manner of solutions. Some suggest that the Sun had more mass and thus shone brighter in its early history. Others propose that our young planet had a thicker atmosphere rich in greenhouse gases or a lower albedo (reflectivity) caused by a lack of cloud cover and a dearth of continental land mass.

Is the Sun at fault?

Most astronomers think the Sun began its life on the main sequence with essentially the same mass it has today. "Predictions from the standard model of solar evolution have not changed appreciably in 30 years," says James Kasting, a planetary scientist at Pennsylvania State University.

Astronomer David Soderblom at the Space Telescope Science Institute in Baltimore concurs. "The assumption that the Sun's mass has changed only marginally over its life is based on the fact that the present-day solar mass loss through the solar wind is tiny," he says. "But we cannot measure such mass loss for other stars, [so] we've had to assume that mass loss is negligible at all ages."



Scientists think the greenhouse effect contributed to early Earth's warmth. Volcanoes erupted carbon dioxide and other gases, which trapped heat radiating from the planet. Recycled rocks kept the process going. MICHAEL CARROLL

> "It's not a paradox — that's hyperbole. It's something [more like] a puzzle."
> — David Stevenson, Caltech

Soderblom notes that some researchers think the faint young Sun problem simply would go away if the early Sun were only 3 to 5 percent more massive than it is today. But he adds that even this much extra mass is hard to reconcile with the current Sun because it likely would leave some observable evidence, such as a higher helium abundance in the core.

Travis Metcalfe at the Space Science Institute in Boulder, Colorado, is one of several stellar astrophysicists who don't believe the Sun's mass has stayed constant since its formation. They think the most promising solution to the faint young Sun problem is that our star was born slightly larger and brighter. They say the star we see today is the result of billions of years of slow mass loss.

"If the Sun was born 5 percent more massive than it is today and slowly lost that excess over the last 4 billion years, you'd still get the same present-day solar structure," says Metcalfe. Therefore, there remains "wiggle room" of at least 5 percent for just how massive our young Sun might have been.

Up in the air

Stevenson thinks the solution to the puzzle lies closer to home. He says that for this issue, at least, scientists understand the Sun — the problem lies with knowledge of our planet. A growing consensus of astrophysicists and earth scientists agrees. These researchers believe that significantly different conditions in Earth's early atmosphere compared with today offer the best solution. The most likely culprits: a mixture of greenhouse gases that warmed our planet

Scientists suspect that a large atmospheric greenhouse effect, a lower albedo, or a more massive Sun kept our entire planet from resembling Antarctica. GUILLAUME DARGAUD

sufficiently despite the young Sun's reduced radiation, or a lower albedo that helped the atmosphere retain more of the Sun's energy.

Many scientists argue that larger quantities of gases such as carbon dioxide, methane, and ethane could have done the trick. Such molecules let sunlight at visible wavelengths pass through unimpeded. The planet's surface absorbed this energy and re-radiated it in the infrared part of the spectrum. The gases then absorbed this longer-wavelength light, warming the young Earth significantly.

"You have to crank up the greenhouse gases to allow the planet to stay clement," says planetary scientist Joseph Kirschvink of Caltech. Theorists tend to focus solely on carbon dioxide as the greenhouse gas of preference, he adds, even though methane traps heat more efficiently and has turned up in fluid inclusions — liquids trapped inside crystals — in Australian rocks dating to 3.5 billion years ago.

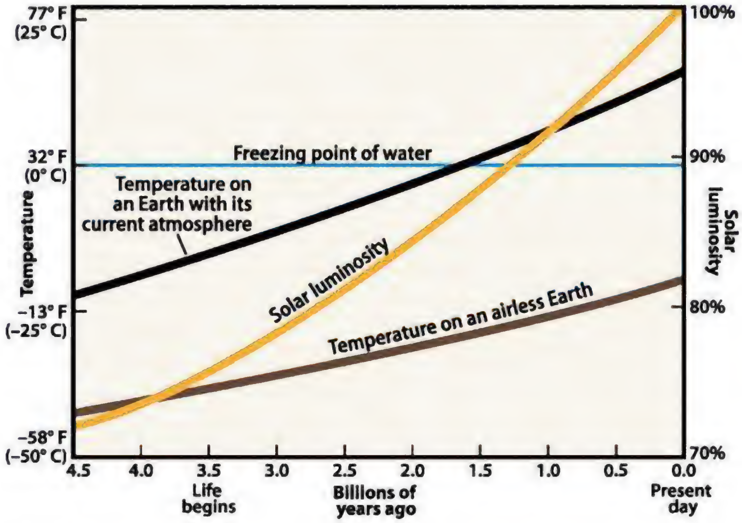
"[Theorists] get into difficulty by saying Earth has to be warm and there may not have been enough greenhouse gases," says Kirschvink. He contends that the greenhouse effect can solve the problem, but he also thinks researchers remain "sufficiently ignorant" about the whole affair and that there's no need to try to pin the solution on a single silver-bullet molecule.

Matthew Johnson, an atmospheric chemist at the University of Copenhagen in Denmark, suggests a different molecule played the key role. He argues that carbonyl sulfide is a superior greenhouse gas to carbon dioxide for warming the young Earth. That's because it absorbs the infrared radiation emitted by our planet better and does so over a broader range of wavelengths.

On a clear day

The second major difference between Earth's early and current atmosphere is the change in cloud cover. Many researchers think large droplets dominated the clouds of the Archean, and theorists argue that such clouds would not have lingered as long as those

The faint young Sun paradox



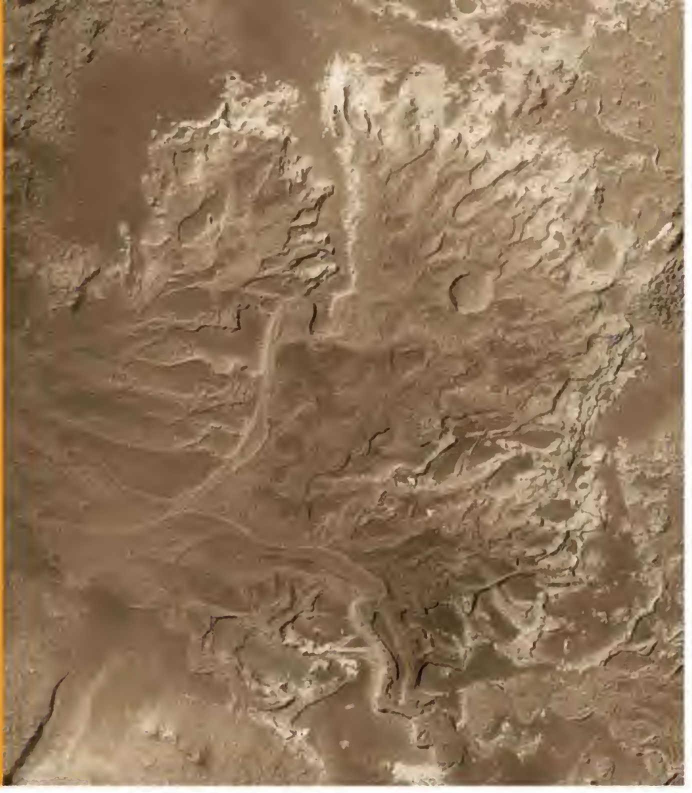
The Sun grows more luminous as its internal structure and composition change over billions of years. The problem: Even with an atmosphere like the current one, Earth's surface temperature should have been far below the freezing point of water for more than half its history. *ASTRONOMY*: ROEN KELLY

today do. Because most clouds reflect incoming sunlight back into space, the relative lack of cloud cover would have lowered Earth's albedo and let in more solar radiation, warming our planet.

The large droplets were caused primarily by bigger condensation nuclei. These nuclei, upon which water vapor condensed, may have been composed of dimethyl sulfide, a biological byproduct of eukaryotes. And these microorganisms, which have distinct nuclei and cellular membrane structures, likely arose during the second half of the Archean. Thus, the emergence of life may have contributed to a more clement Earth.

It doesn't take something as complex as life, however, to reduce Earth's cloud cover. Friction between the oceans and the crust induced by tides has significantly slowed our planet's rotation rate

LEARN MORE The Sun's luminosity will continue growing for several billion years. To purchase a PDF package of *Astronomy* articles that look at the current state of our star and what the future may hold, visit **www.Astronomy.com/extracontent**.



Although it lies much farther from the Sun, Mars also was warm enough in its early history to support liquid water. This fossilized delta at Eberswalde Crater clearly shows past water flow across the martian surface. NASA/JPL/MSSS

since the Moon formed 4.5 billion years ago when a Mars-sized object collided with the proto-Earth. Days during the Archean may have been as short as 14 hours. And computer models show that as Earth's rotation speeds up, cloud cover goes down.

While Earth was spinning faster, so was the Sun. Observations of young Sun-like stars show that despite their lower luminosities, they rotate more quickly and generate more activity than our Sun. According to Nir Shaviv, an astrophysicist at Hebrew University of Jerusalem, a more active Sun would have produced a stronger stream of charged subatomic particles known as the solar wind. And these particles, in turn, would diminish the number of "cosmic rays" that reach Earth from beyond the solar system.

Shaviv contends that fewer cosmic rays would mean fewer ions in the young Earth's atmosphere, resulting in less cloud cover. Still, Johnson says the link between cosmic rays and cloud cover remains controversial, even in the modern atmosphere.

Another factor affecting our planet's albedo is the relative amount of land and water. Geologists think that continents likely covered as little as 3 percent of Earth's surface during the Archean, just one-tenth of what they do now. The expansive dark waters would have lowered the planet's albedo and thus intensified the warming effects of incoming solar radiation.

Under pressure

But some researchers think clouds and albedos are extraneous to a more significant finding about the Archean — the eon may have had a substantially higher atmospheric pressure than previously believed. And the chief contributor to this increased pressure is the atmosphere's most abundant constituent: molecular nitrogen.

"We now have [nearly] 80 percent nitrogen in the atmosphere," says Colin Goldblatt, a geoscientist at the University of Victoria in British Columbia. "But Earth's early atmosphere would have been some 90 percent nitrogen." Much of this excess nitrogen eventually found its way into Earth's crust and mantle. Some bacteria convert atmospheric nitrogen into a form that plants can use. This nitrogen gets incorporated into organic matter, which then gets buried and eventually can reach the mantle.

Although nitrogen is not a greenhouse gas in itself, Goldblatt explains that greater amounts of this molecule in the atmosphere increase the pressure, and this makes existing greenhouse gases more effective in absorbing heat radiated from Earth's surface. Kasting adds that larger pressures also make collisions more likely, allowing molecular hydrogen to act as a greenhouse gas and boosting the efficiency of carbon dioxide.

Blue waters for a Red Planet

Earth isn't the only planet that managed to overcome a faint young Sun. Although Mars is cold and dry today, ample geological evidence shows that the Red Planet was much warmer and wetter in the distant past. And this occurred despite the fact that Mars lies more than 50 percent farther from the Sun and receives less than half the solar radiation that our planet does.

"It took a lot of water to form Mars' valley networks," says Kasting. These systems consist of channels that typically measure 0.6 to 6 miles (1 to 10 kilometers) wide and a few hundred feet (100 to 200 meters) deep. The valley networks have well-developed tributary systems that look remarkably similar to river systems on Earth.

Although an impact with a large comet or asteroid could have raised global temperatures on Mars enough to allow water to flow on the surface temporarily, Kasting says this scenario doesn't fly for some martian features.

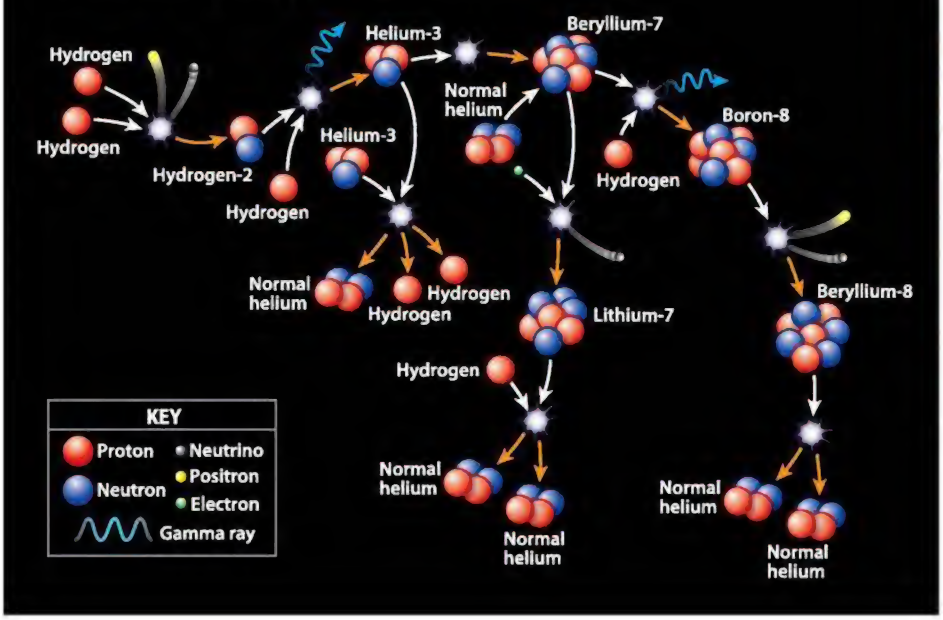
"[The impact hypothesis] fails to generate enough water to carve the larger valleys seen on Mars," he says. "It doesn't just fail by a small amount — it fails spectacularly. This can be demonstrated either by simple analogy to features like the Grand Canyon on Earth or by detailed hydrologic analysis."

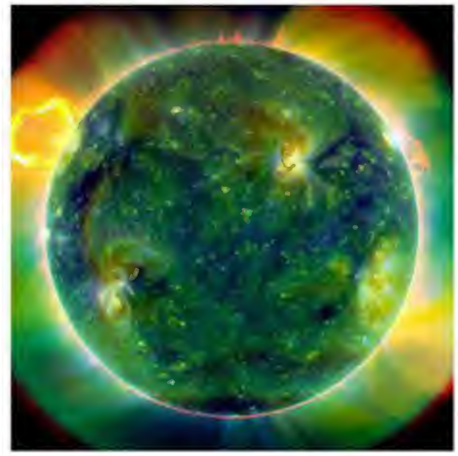
Kasting and his colleagues have developed new climate models for Mars that show warm average surface temperatures were possible across the globe as far back as 3.8 billion years ago, when the Sun's luminosity was only 75 percent of what it is today. The

This 2.1-billion-year-old banded iron formation consists of distinct layers of sedimentary rock laid down in seawater. Such rocks are among the best evidence that liquid water existed on Earth's surface billions of years ago. ANDRÉ KARWATH

Black smokers on Earth's seafloor (this one lies near the Galapagos Islands) suggest that life could have remained vibrant even during episodes when thick layers of ice may have covered Earth's surface. UCSB/UNIVERSITY OF SOUTH CAROLINA/NOAA/WHOI

A changing Sun





The Sun generates energy by converting hydrogen into helium through the so-called proton-proton chain (left). The reaction rate rises as the number of particles in our star's core falls, and that number has been decreasing as the conversion process continues. The result: Today's Sun (above) generates more energy than before, so it is more luminous.
ASTRONOMY: ROEN KELLY (ILLUSTRATION); NASA/SDO/AIA (PHOTO)

models use a combination of greenhouse gases — including carbon dioxide, hydrogen, methane, and nitrogen — and require a relatively dense atmosphere having at least twice Earth's current atmospheric pressure to get these clement conditions.

Some researchers contend that impacts or interactions with the solar wind would have stripped away a dense martian atmosphere quickly. Still, Kasting says the valley networks we now see on Mars' ancient heavily cratered terrain argue otherwise.

Toward a solution

So when will planetary scientists finally resolve the faint young Sun paradox? For geophysicists, "It comes down to the geologic record," says Goldblatt. "The further back in time, the fewer rocks are available. But researchers are learning to get more and more out of the rocks that do exist." He says the geologic record preserves the state of Earth's surface fairly well dating back to about 3.5 billion years ago. Although evidence suggests widespread glaciation existed 2.9 and 2.4 billion years ago, there was little in between. Goldblatt thinks the only good explanation is a stronger greenhouse effect during the Archean.

Much of the geologic evidence for water on Earth's surface comes from sedimentary rocks up to 3.8 billion years old. For example, banded iron formations, which consist of alternating thin layers of iron oxides and iron-poor rocks, formed in seawater. Free oxygen produced by blue-green algae combined with dissolved iron to create the iron-rich layers; the opposing layers accumulated during periods when the algae died off from an excess of free oxygen.

Other signs of liquid water include so-called pillow lavas, created when molten lava pushes forth from the ocean floor, and ripple marks in the sediments themselves caused by wave action in Earth's ancient oceans.

Despite the evidence for liquid water, Stevenson says there's nothing in the geologic record that excludes the possibility of significant ice cover at times during this early epoch. He also notes that there's nothing in our understanding of how life originated that requires Earth's entire surface to be warm and void of ice. Some scientists believe that life arose around hydrothermal vents deep under the sea, where surface conditions wouldn't matter.

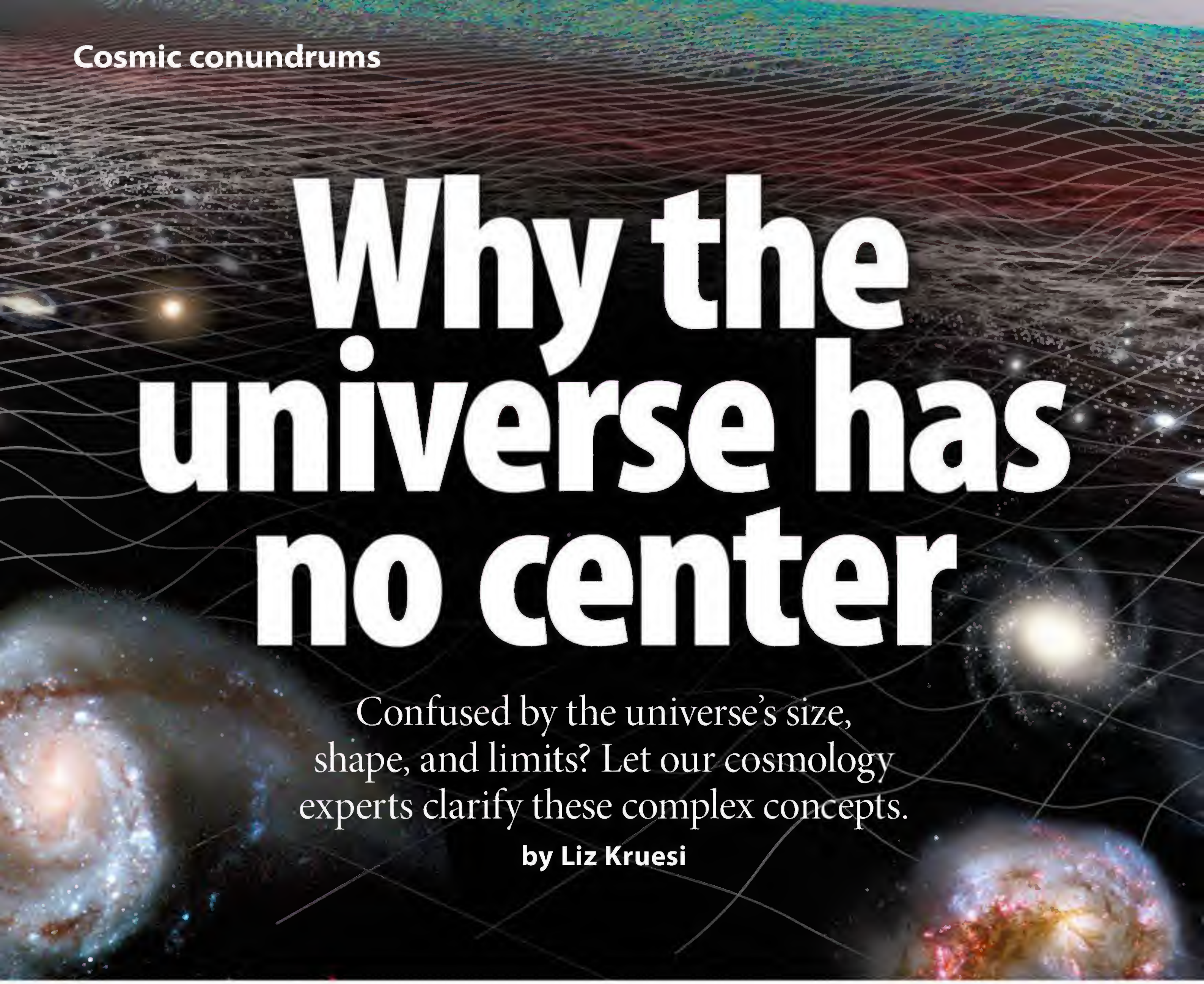
Planetary scientists can point to an array of greenhouse gases, a lower planetary albedo, or some combination of the two as reasons why Earth remained warm despite a faint young Sun. Darrell Strobel at Johns Hopkins University in Baltimore says that in the broadest sense, geologists seem to think the issue has been solved, whereas astronomers and astrophysicists believe it's still an open question. "The climate models used for Earth's early climate are primitive, and whenever something doesn't work out, like magic, [theorists] introduce clouds," says Strobel. "You can solve the problem with ad hoc assumptions, but whether you have the right solution is another question."

> "The climate models . . . are primitive, and whenever something doesn't work out, [theorists] introduce clouds." — Darrell Strobel, JHU

Yale University astrophysicist Sarbani Basu thinks the final answer to this decades-long faint Sun conundrum may have to wait awhile. She believes astronomers first need to compare what we know about the young Sun with how quickly stars in the early stages of their lives lose mass — and precise observations of youthful Sun-like stars are still in their infancy.

Despite the progress scientists have made trying to resolve this issue during the past 40 years, it seems likely that the faint early Sun and its interaction with our own young planet will remain a paradox — or at least a good puzzle — for the foreseeable future.

WATCH SOME OF THE LATEST VIDEOS OF THE SUN'S ONGOING ACTIVITY AT **www.Astronomy.com/toc.**



Cosmic conundrums

Why the universe has no center

Confused by the universe's size, shape, and limits? Let our cosmology experts clarify these complex concepts.

by Liz Kruesi

▲ The universe began 13.77 billion years ago. That moment marked the start of space and time, but this beginning was not a blast into empty space as many portray it.

The universe's beginning did not involve an explosion into nothingness — even though many media sources (including *Astronomy*) and science organizations often illustrate such a blast. This common visual and other misportrayed aspects of what scientists know about our cosmos often lead to confusion and inspire questions. The concepts are complex and difficult to understand, and the desire to graphically describe them causes this confusion. Plus, the "Big Bang" is actually a poor name for the universe's start.

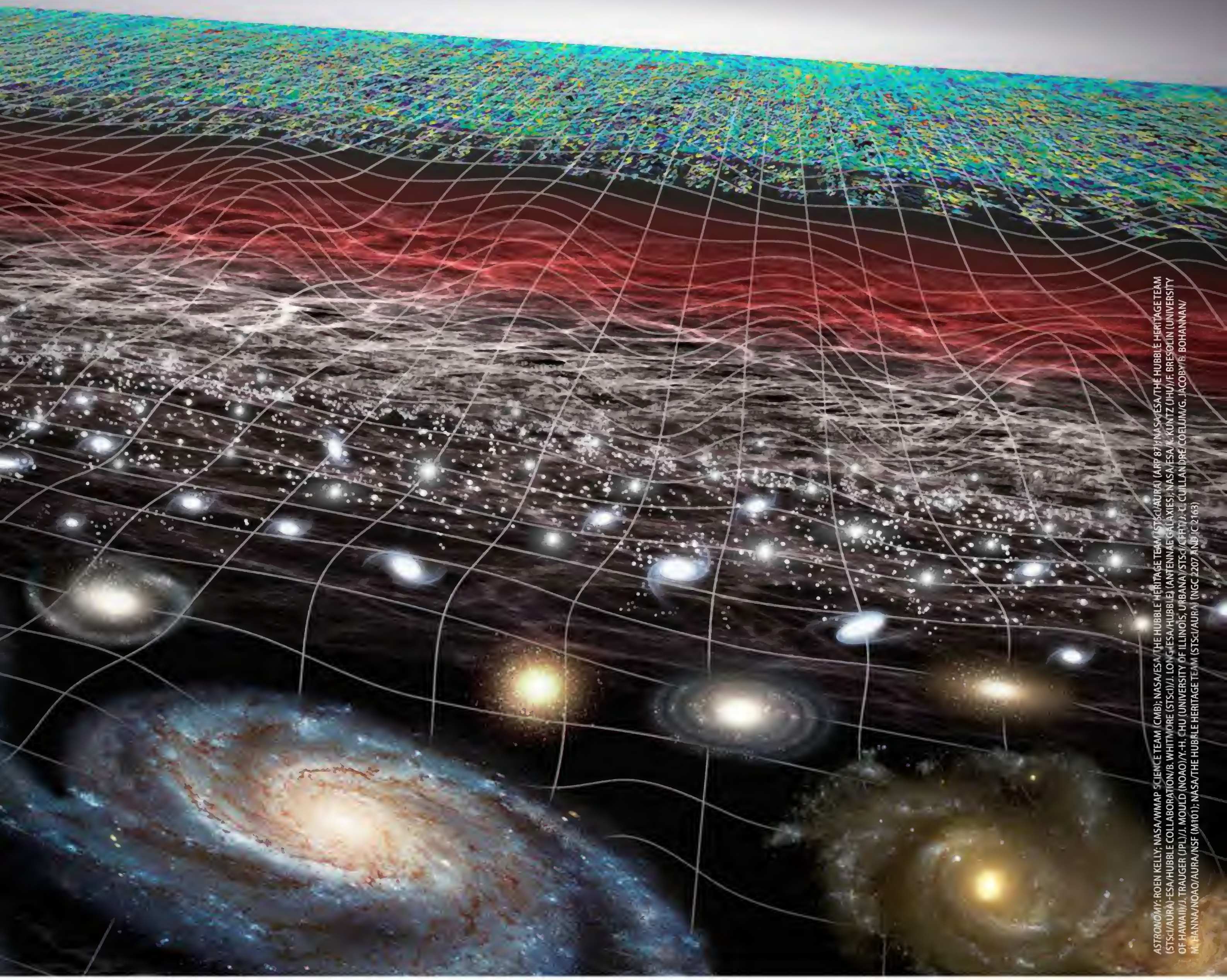
In the mid-20th century, astronomers battled over which of two major theories correctly described cosmic evolution: the Steady State model (the universe had no beginning or end) or what's now known as the Big Bang model. Fred Hoyle, a leading Steady State theorist, used the phrase *Big Bang* while describing the competing models on a radio station. He wanted to use a term that was dramatic — and one that stuck — so that people could tell the two theories apart. Unfortunately, "Big Bang" certainly stuck, and now it leads to confusion.

So, why do scientists believe that the Big Bang, or expanding universe, theory best explains the cosmos? In 1929, Edwin Hubble showed that more-distant galaxies seem to be traveling away from Earth at faster rates. This finding led astronomers to the conclusion that the universe must be expanding.

And ever since, the public has questioned whether Earth is at the center of this expanding universe; after all, that expansion means everything moves away from us, right? But this motion is all a matter of viewpoint. An observer in any galaxy would also see everything moving away from her.

This is just one of many common confusions and puzzlements in the mind-bending field of cosmology. So, here, with the help of astrophysics experts, we hope to clear up a few of these conundrums.

The idea for this article came to **Liz Kruesi,** *an* Astronomy *associate editor, after reading hundreds of "Ask Astro" questions.*



ASTRONOMY: ROEN KELLY; NASA/WMAP SCIENCE TEAM (CMB); NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA) (ARP 87); NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)-ESA/HUBBLE COLLABORATION/B. WHITMORE (STScI)/J. LONG (ESA/HUBBLE) (ANTENNAE GALAXIES); NASA/ESA/K. KUNTZ (JHU)/F. BRESOLIN (UNIVERSITY OF HAWAII)/J. TRAUGER (JPL)/J. MOULD (NOAO)/Y.-H. CHU (UNIVERSITY OF ILLINOIS, URBANA)/STScI/CFHT/J.-C. CUILLANDRE/COELUM/G. JACOBY/B. BOHANNAN/M. HANNA/NOAO/AURA/NSF (M101); NASA/THE HUBBLE HERITAGE TEAM (STScI/AURA) (NGC 2207 AND IC 2163)

MEET THE EXPERTS

Scott Dodelson
He is a professor at the University of Chicago and the head of the Theoretical Astrophysics Group at Fermi National Accelerator Laboratory in Batavia, Illinois. His research focuses on investigating theories for dark energy and studying the cosmic microwave background radiation. FERMILAB

Joanna Dunkley
She is a lecturer in astrophysics at the University of Oxford. She studies the cosmic microwave background as a member of the Wilkinson Microwave Anisotropy Probe and Planck spacecraft teams and also works with the Atacama Cosmology Telescope in Chile. LOUISE DUNKLEY

Mario Livio
He is an astrophysicist at the Space Telescope Science Institute in Baltimore, which runs the Hubble Space Telescope. There, he concentrates on studying exploding stars and learning about dark energy. ZOLT LEVAY

John Mather
He was co-awarded the 2006 Nobel Prize in physics for his work studying the cosmic microwave background radiation. He is a researcher at NASA's Goddard Spaceflight Center in Greenbelt, Maryland, working on the James Webb Space Telescope, scheduled to launch in 2018. DAVID FRIEDLANDER (NASA)

Mark Trodden
He is a professor of physics and co-director of the Center for Particle Cosmology at the University of Pennsylvania. His research touches on the intersection of particle physics and cosmology and investigates what the mysterious dark matter and dark energy might be. STEVE SARTORI/SYRACUSE UNIVERSITY

Edward (Ned) Wright
He studies cosmology and the infrared universe at the University of California, Los Angeles. He is the principal investigator of NASA's Wide-field Infrared Survey Explorer, which launched in 2009. TODD CHENEY/ASUCLA PHOTOGRAPHY

How would you explain what the Big Bang was?

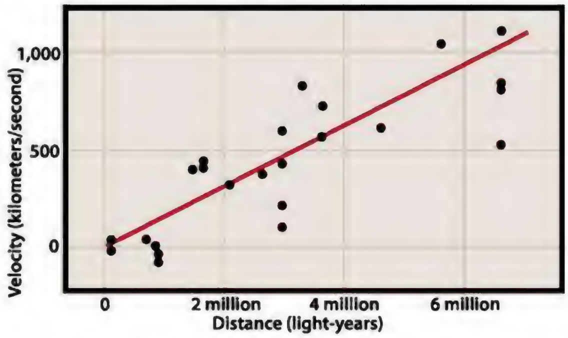
John Mather: There wasn't any bang, and the universe did not "come into existence" like a giant firecracker going off on July 4. When we hear the words, we can't help ourselves — we picture a firecracker or a grenade blowing up at a particular place and time. … Practically speaking, the Big Bang is everywhere; we and all our atoms and everything are inside it.

Joanna Dunkley: The Big Bang is this extremely fast expansion of space that grows. … The space that takes up the universe that we can see now was very, very small at the Big Bang. It was happening everywhere.

Edward (Ned) Wright: The Big Bang is a singularity that extends throughout all space at one particular time. We call that time "t=0." So the Big Bang was everywhere, not at some special location.

Mark Trodden: It was the appearance of all space and time at once. You can think of it as an explosion at a point in time — it happens everywhere at a certain time. You can't point to a "where" it happened, but you can point to a "when."

Evidence of expansion



In 1929, Edwin Hubble found that galaxies farther away are receding faster, leading scientists to conclude that the universe is expanding. *ASTRONOMY*: ROEN KELLY, AFTER EDWIN HUBBLE/PNAS

What other evidence indicates an expanding universe?

JD: The cosmic microwave background [which is radiation that fills the universe; its temperature is 2.725 kelvin above absolute zero]. Just its existence tells us that something like the Big Bang had to have happened. … We see light hitting us from every direction in space. Anywhere we look in the sky, we see this microwave light. And the real signature of the Big Bang is that it's the same temperature everywhere, which means it had to be in contact with itself sometime in the past. … It must have been connected [and thus much smaller].

Mario Livio: When we look at the cosmic microwave background, it is extraordinarily isotropic. It's the same in every direction to better than one part in 10,000.

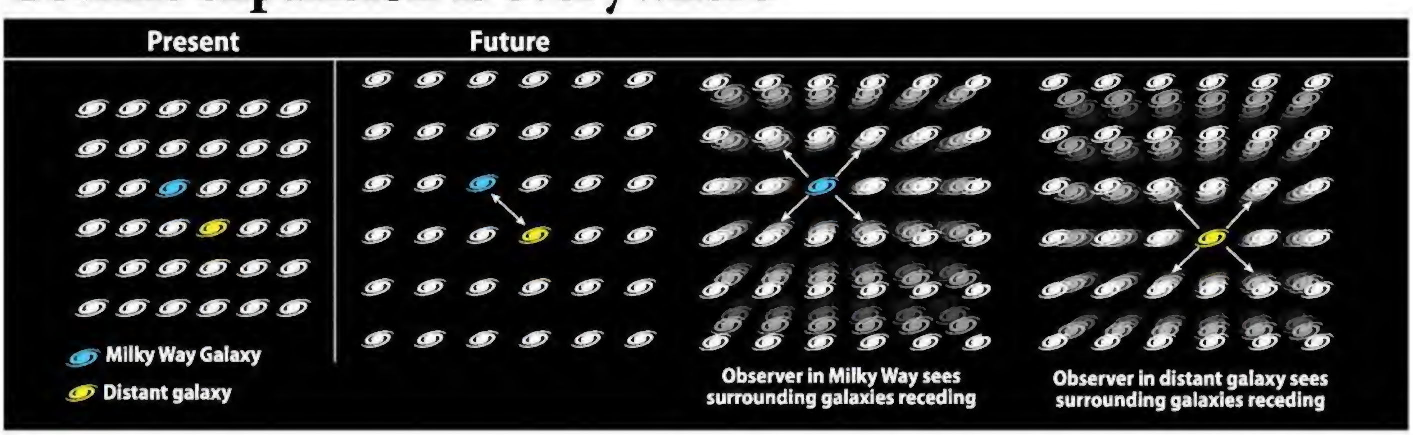
What came before the Big Bang?

MT: Within general relativity, time began at the Big Bang. If we believe that, then the conversation is over. But that's not a good enough response. The universe was extremely hot and dense the further back in time you go. Things were so crammed together that you need quantum mechanics to explain it. But you also need general relativity because it's so dense. We don't have a verified theory that explains how these two things work together. String theory is a candidate to explain this, but we have no solutions yet.

EW: We cannot say. A singularity means that we can only speculate about what came before. Inflation [see illustration on p. 31] is a theory that replaces the singularity with a rapid exponential expansion, which also erases all evidence of what came before.

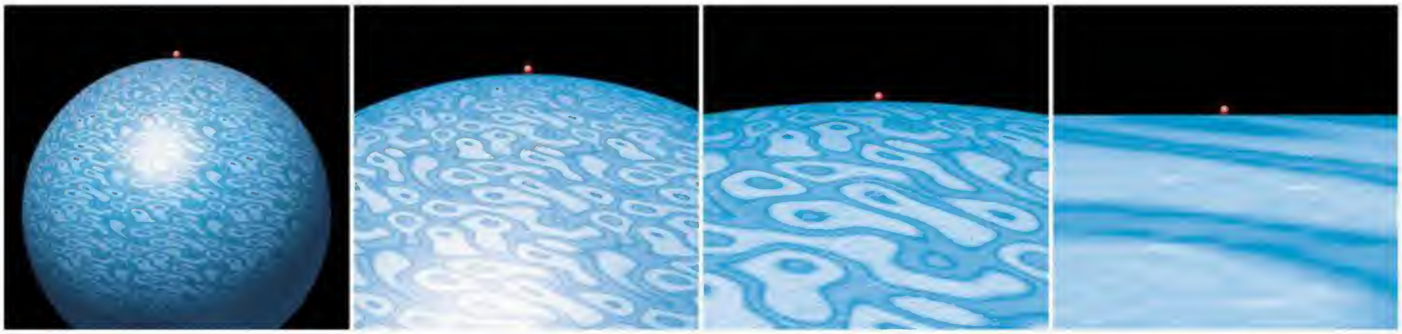
JD: We think that time and space are closely connected. And so … you can't just turn the clock back to before the Big Bang because our concept of time doesn't really extend to a point past the Big Bang.

Cosmic expansion is everywhere



As the universe expands, it pulls galaxies away from one another. No matter what galaxy an observer is in, she will see all others receding from her. *ASTRONOMY*: ROEN KELLY

Inflation super-expanded the cosmos



Inflation occurred a fraction of a second after the Big Bang. A curved surface expands by a factor of three in each subsequent panel. The sphere in the last view appears nearly flat. To relive cosmic inflation, repeat this expansion 87 more times. Scientists say that inflation explains why the universe is geometrically flat and the cosmic microwave background is almost the same temperature everywhere. *ASTRONOMY*: ROEN KELLY

How far back can scientists explore?

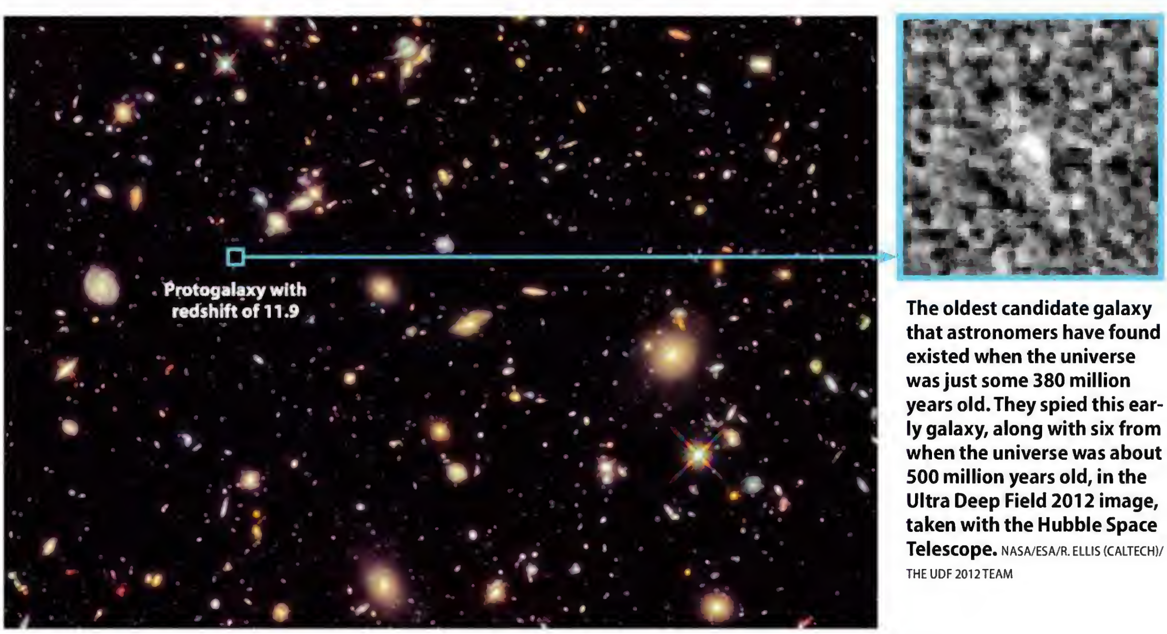
ML: In some sense, you can think of inflation as being the "bang." Inflation is this very fast expansion that happened when the universe was a tiny fraction of a second old. In recent years, we started talking more about what happened at inflation, and we tried to de-emphasize what happened before inflation simply because inflation kind of erases the signs of the initial conditions.

JD: If the universe expanded extremely quickly in the first fraction of a second — the inflationary period — then it would have sent out ripples in space-time itself. We call them gravitational waves. We're really trying to find these waves, and space itself would be sort of stretching and shrinking in time as a gravitational wave passes through.

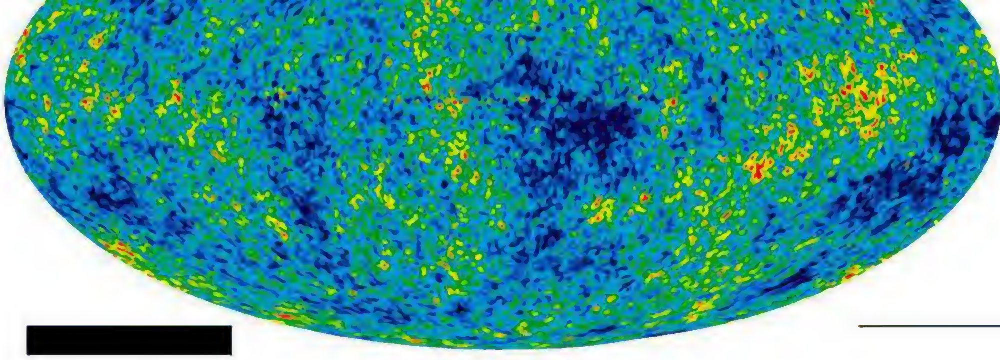
JM: Astronomers are hot on the trail of yet more information about the cosmic microwave background that might be a little polarized [meaning the radiation's oscillation would have a specific direction] if there were gravitational waves in the early universe.

ML: Looking forward, how can we see something that directly will show us that there was inflation? This enormous expansion generated gravitational waves in the universe. And those [waves] would have left a characteristic signature in the cosmic microwave background [called B-mode polarization]. They have a particular pattern. If we actually detect this, it would be unbelievable. We'd have observational evidence for something that happened when the universe was 10^{-32} second old. This would be phenomenal.

Now that we've cleared up details about the cosmos' start and what the Big Bang was — and wasn't — let's move on to addressing confusion about the universe's shape. Scientists rely on many methods to distinguish cosmic geometry; they're trying to discern the forest by the trees. When they explain aspects of the universe, however, the examples they use occasionally can cause more confusion. One such case is comparing the fabric of space-time to the surface of a balloon, which sometimes leads to the (incorrect) assumption that we, the observer, are at the center of the universe.



The oldest candidate galaxy that astronomers have found existed when the universe was just some 380 million years old. They spied this early galaxy, along with six from when the universe was about 500 million years old, in the Ultra Deep Field 2012 image, taken with the Hubble Space Telescope. NASA/ESA/R. ELLIS (CALTECH)/THE UDF 2012 TEAM



The cosmic microwave background provides extremely strong evidence that the universe is expanding. The different colors indicate slightly varying temperature regions — with less than a 1 in 10,000 difference. To be so similar in temperature, the areas must have been much closer in the past. NASA/WMAP SCIENCE TEAM

We see galaxies receding, so aren't we at the universe's center?

JM: Ever since Columbus and Copernicus, we have been noticing that our privileged position is only a matter of limited visibility and perspective. In fact, we can calculate what an astronomer living in another galaxy would see, and she would measure exactly the same chart that Hubble did [see p. 30], and she would also think she was at the center of her own expanding universe.

JD: Imagine stretching a long piece of elastic. If you look at that bit of elastic, it's not stretching from the center; … it's stretching from everywhere along that elastic. We think of space as being a bit like that elastic. Anywhere you were in the universe, you would see the same expansion happening. You think you might be at the center of it, but it's just the viewpoint.

Draw spots all along the [elastic] band. As you stretch that band, the spots themselves are not really moving in that space, but they appear to move away from each other. … Pretty much all galaxies are, more or less, just sitting in the "cosmic flow." But they're not moving compared to the motion of space.

Scott Dodelson: As Einstein (and Galileo before him) taught us, motion is relative. … An observer in any distant galaxy would see Earth moving away from her at a speed given by Hubble's law (i.e., equal to about 140 miles per second if the galaxy was 10 million light-years away from us and at larger speeds if it were farther away) just as we see other galaxies moving away from us.

Although distant galaxies appear to be receding from Earth, they are actually receding from each other. This is because the fabric of space-time itself is expanding and the galaxies just ride along that flow. No matter what galaxy you live in, you see the same thing: other galaxies receding. The universe does not have a center.

But does the universe have an edge?

MT: In our cosmological theories, we don't expect the universe to have an edge, so it must either be infinite or a finite space without an edge, like the surface of a sphere. It is possible to look for evidence in cosmological data for the universe having a finite size, but so far scientists see nothing in the data that suggests this or an edge.

JM: For the moment, almost all astronomers are using a "standard model" of the early universe that goes infinitely far in all directions and is almost the same density everywhere. And it fits all the observations, even if most of us can't imagine how it would get "started."

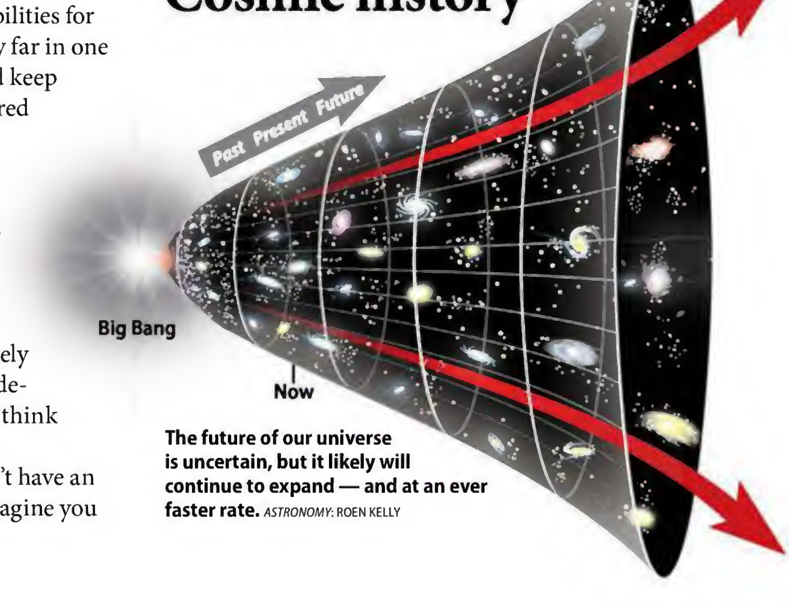
SD: There is no "edge" in the universe, no place where the universe stops. There are several possibilities for what would happen if you could travel very far in one direction in the universe. Either you would keep going forever, seeing previously undiscovered territory (the universe is infinite), or you would return to a place you previously visited (the universe is finite, with a complicated topology, just like the edge of a video game where you leave on one side of the screen and re-enter on the other).

JD: [It] could be that the universe is infinitely big. It could just stretch on — up, down, sideways — infinitely. … Even for a scientist, I think that's not necessarily appealing.

You also can have a case where you don't have an edge, but the universe actually is finite: Imagine you can take a piece of paper [and] roll it into a tube and connect up the two long sides, and then roll it round into a donut. … That piece of paper now doesn't have any edges, and it has no center, but it is actually finite and has a size.

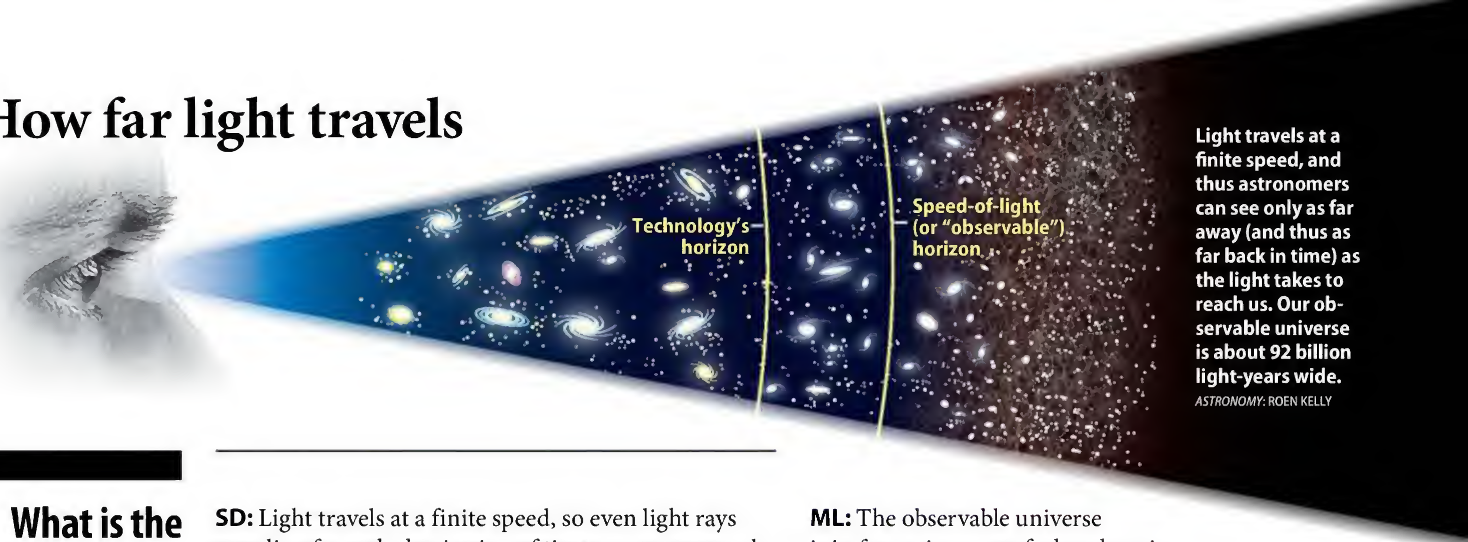
So, scientists know the universe is either infinite or finite and huge. When discussing the cosmic size, they often include the adjective visible *or* observable *before "universe." This is a smaller portion of the cosmos, dictated by the universe's age of 13.77 billion years.*

Cosmic history



The future of our universe is uncertain, but it likely will continue to expand — and at an ever faster rate. *ASTRONOMY*: ROEN KELLY

How far light travels



Light travels at a finite speed, and thus astronomers can see only as far away (and thus as far back in time) as the light takes to reach us. Our observable universe is about 92 billion light-years wide. *ASTRONOMY*: ROEN KELLY

What is the "observable universe"?

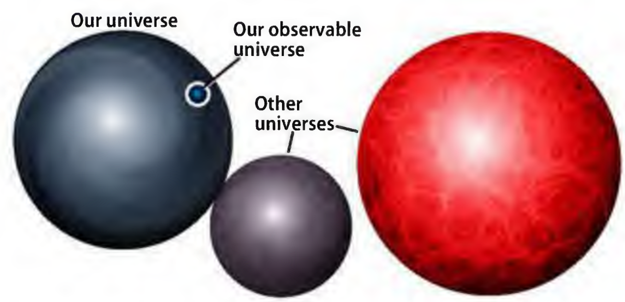
SD: Light travels at a finite speed, so even light rays traveling from the beginning of time can traverse only a finite distance. This distance defines the radius of the "observable" or "visible" universe. Presumably, the universe is quite a bit larger than this, but we have no information about the universe beyond this fundamental distance.

ML: The observable universe is in fact a tiny part of what there is.

Does the observable universe have an edge?

EW: Yes, this edge is our "horizon." It is 46 billion light-years away from us in all directions.

MT: It is the largest distance from which light emitted now can ever reach us. Light emitted today, farther away, won't reach us ever.



Inflation may have created multiple universes. To detect the existence of another one, astronomers look for a radiation signature that could indicate one slammed into our universe in the past. *ASTRONOMY*: ROEN KELLY

How can light travel from 46 billion light-years away if the universe is only 13.77 billion years old?

MT: It is common for people to worry about this because they've heard that in special relativity, if you take two things that pass each other, their speed must not exceed *c* [the speed of light] relative to them. But once you have space that is curved in general relativity and we talk about how space itself is stretching, the usual idea of a speed limit isn't valid anymore.

ML: People sometimes think that everything cannot move faster than light. Well, there is no limit on how fast space-time can stretch. … The expansion can be, and was, much faster than the speed of light.

So, after 13.77 billion years, the horizon spans some 92 billion light-years. Scientists' detectors can see nearly to the edge of this observable universe and look for characteristics of the cosmos. The future of observational cosmology includes looking for clues to the universe's shape and size, along with the search for gravitational waves in the cosmic microwave background.

What type of observations are cosmologists looking for?

JD: If [the cosmos] is finite, then … you could look in two different directions of the universe and see the same thing because you'd see light basically traveling around the universe and back again. This is similar to how on the surface of Earth you can set off in one direction and come back round and meet yourself.

One particular pattern [you can see is] circles in the sky. Imagine taking two beach balls and pushing them together really hard. Where they meet would be a circle. It's actually really cool.

ML: It's actually hard for inflation not to produce a multiverse. There is some small probability that our universe could have collided with another because another one would just pop near enough ours that these universes would have basically banged into each other. This would have happened already, and we could in principle see some signature in the cosmic microwave background. We haven't yet. Otherwise, we might expect that the existence of a multiverse would produce some testable predictions in the observable part of our universe.

Our universe could be one of many. And in those other universes, perhaps there are people — or beings, anyway — trying to understand their cosmos' shape, size, and beginning. And maybe they're also working to clear up confusion and puzzlement about the mind-bending aspects of their own universe.

CONSERVING STELLAR FUEL

Q: I HAVE ALWAYS HEARD THAT EVERYTHING WE SEE IS "STAR STUFF" FROM PREVIOUS STARS THAT DIED AFTER CONVERTING THEIR HYDROGEN INTO HEAVIER ELEMENTS. SO HOW IS THERE ANY HYDROGEN LEFT FOR THE SUN AND PLANETS?

William Manthey, *Beacon Falls, Connecticut*

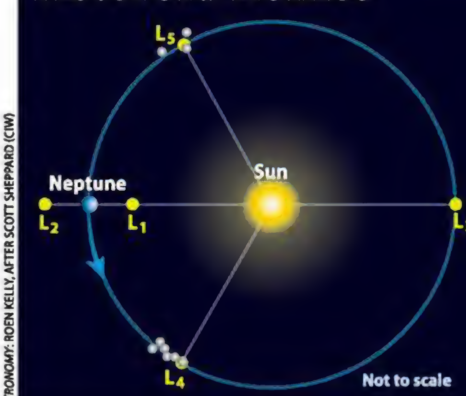
A: That's a great observation. Hydrogen is the main source of fuel for stars like the Sun. However, the atoms near the center of a star are the only ones that participate in the fusion reactions that power it. These atoms make up only a small fraction of all those in a star. In fact, more than 90 percent of the atoms in a star like the Sun are hydrogen, and less than 10 percent of the hydrogen atoms in a star when it was born fuse into heavier elements during its 10-billion-year lifetime. When the fusion reactions that power the Sun cease, our star will cast off about half of its material and its core will evolve into a tiny, hot white dwarf star.

There's more to the story, too. The Milky Way is slowly growing larger as clouds of hydrogen gas steadily rain down on its disk. This material mixes with the atoms recycled from earlier generations of stars, and this combination then forms into new stars and planets, continuing the cosmic circle of life.

Ian Roederer
The Carnegie Observatories, Pasadena, California

Planetary nebulae mark the ends of Sun-like stars' lives. After a star has exhausted the fuel within its core, it casts off about half of the leftover material — plenty to create future generations of celestial bodies. This image of the Cat's Eye Nebula (NGC 6543) shows a lot of hydrogen (red), nitrogen (green), and oxygen (blue). J. P. HARRINGTON AND K. J. BORKOWSKI (UNIVERSITY OF MARYLAND)/NASA

Asteroid homes



ASTRONOMY: ROEN KELLY, AFTER SCOTT SHEPPARD (CIW)

Neptune's and the Sun's gravity balance out in five regions; each planet has five such areas with respect to our star (labeled L1 through L5). In Neptune's L4 area, six Trojan asteroids orbit the Sun ahead of the world. (In the planet's L5 region, three such asteroids trail Neptune in its orbit around our star.) Both Neptune's L4 and L5 span about 2 billion miles (3.2 billion kilometers), and thus the asteroids have enough room to move within the area that collisions are extremely rare.

Q: HOW CAN SIX TROJAN ASTEROIDS RESIDE IN NEPTUNE'S L4 REGION WITHOUT COLLIDING?

Jim Weith
Mission Viejo, California

A: The gravity of a planet, its star, and the centrifugal force associated with the planetary orbit nearly balance in five regions near the planet's path where an asteroid (or spacecraft) could orbit safely. These areas are nicknamed L1 through L5 after the French mathematician Joseph Lagrange, the first to catalog all five points.

Calculations show us that a planet's gravity can often destabilize the orbits of nearby asteroids and comets, flinging them away or sending them crashing into the Sun or into that planet. Some also could be captured within one of the stable regions. Neptune's L4 area spans a large region in space, and it has a lot of room for Trojan asteroids to orbit within and not crash into each other. The objects in these orbits span a zone about 30° across as viewed from the Sun (see illustration above). Given that these orbits are at about the same distance from the Sun as Neptune, L4 spans about 2 billion miles (3.2 billion kilometers), or about 22 times the radius of Earth's orbit, for example.

We have discovered only a handful of Neptune Trojans, but we think the ones we see are just the tip of the iceberg, so to speak; there are probably many more smaller asteroids orbiting in the L4 region, and these plentiful small objects may indeed collide over billions of years. We're also not certain exactly how the Neptune Trojans formed, but colliding asteroids that break apart may have played a role.

Marc Kuchner
NASA's Goddard Space Flight Center, Greenbelt, Maryland

Q: HOW MASSIVE ARE GLOBULAR CLUSTERS' STARS? THEY'RE OLD, SO THEY CAN'T BE TOO BIG, RIGHT?

David Oertel
Bangor, Maine

A: Astronomers measure stellar masses in terms of the Sun's mass (just shy of 4.4 quadrillion quadrillion pounds [2.0 quadrillion quadrillion kilograms]). Most stars in globular clusters today are less massive than the Sun, but some exceptions exist. Thus, the answer to your question comes in three parts — normal stars, "blue stragglers," and stellar remnants.

Normal single stars in globular clusters range from about 8 to 90 percent of the Sun's mass. The lower value comes from a

fundamental law of stellar physics; it corresponds to the limit at which collapsing objects can fuse lighter elements into heavier ones within their cores. Astronomers classify objects with less than 8 percent of the Sun's mass (but more massive than planets) as brown dwarfs. We have yet to observe brown dwarfs in globular clusters, however, because they're too faint to see even with today's most sensitive optical instruments. New infrared capabilities on the Hubble Space Telescope, and soon the James Webb Space Telescope, should find them if they exist.

The best estimate of the upper mass limit comes from analyzing an eclipsing binary star system in the globular cluster 47 Tucanae. We can measure the stars' masses and radii from observing their orbits. The stars in this binary have masses of 87.6 percent and 85.9 percent of the Sun's mass. They lie right at the end of the main sequence portion of stellar evolution and so provide an upper limit to the masses of normal stars.

Blue stragglers are stars that form via either mass transfer between two members of a close binary or the merger of two stars. The extra mass rejuvenates the older suns and creates a brighter and hotter (bluer) star — hence the name. A blue straggler can have a mass up to twice a single "normal" star in a globular.

Stellar remnants can be more massive than normal stars. A white dwarf — the final product of a Sun-like star's evolution — can range from 0.5 to 1.4 solar masses. Scientists have observed white dwarfs in globular clusters, but the most massive ones weigh in at only 60 percent of the Sun's mass; we haven't been able to detect more-massive white dwarfs with current technology.

Neutron stars — compact objects that are an end product of massive stars — start at 1.4 solar masses and can reach up to about 3. We have seen pulsars — rapidly rotating neutron stars with radiation beams pointed toward Earth — in several globular clusters. We also have evidence that stellar-mass black holes exist in globular clusters. These objects probably range from 10 to 20 solar masses.

Aaron Dotter
The Australian National University, Canberra

Our solar system is moving toward the star Lambda (λ) Herculis, some 370 light-years away. ASTRONOMY: ROEN KELLY

Q: EARTH SPINS AS IT ORBITS THE SUN, AND THE SOLAR SYSTEM IS ORBITING THE GALACTIC CENTER. SO, IF I GO OUTSIDE AND LOOK UP, IN WHAT DIRECTION ARE WE HEADING?

Dale Peterson
Oak View, California

A: When you gaze up at the constellation Hercules, you are looking out the front window of the spacecraft called Earth. Our planet is hurtling at some 45,000 mph (72,000 km/h) toward the star Lambda (λ) Herculis, which lies about 370 light-years away. (Textbooks often state the bright star Vega, to generalize the direction.) At this speed (and if Lambda Herculis remained in the same position), it would take some 5.5 million years to reach this point in space; it's not worth thinking about, so just enjoy the ride.

The Sun, the planets, and all the other flotsam and jetsam that constitute the solar system are so insignificant that we can consider the entire mass a point in space. No matter where you might stand — on the Moon, Jupiter's Io, Mars, or any location on Earth — you are still traveling in the same direction.

We accept that our planet spins on its axis once a day almost as a matter of faith. Earth and the Moon gyrate around the Sun, completing a full orbit in approximately 365 days. Our planet experiences many other motions, such as precession and nutation, but none has any impact on the inexorable flight toward Lambda Herculis.

But wait, there's more! The Sun and its attendant bodies slowly bob up and down through the Milky Way's arm. Our planetary system also orbits the galactic center about every 220 million years. And don't forget that our galaxy is on a collision course with the Andromeda Galaxy (M31). Our entire local cluster of galaxies is also in motion. The best part — no motion sickness.

Ray Shubinksi
Contributing Editor

Q: HOW OLD IS THE MILKY WAY, AND HAS IT MERGED WITH OTHER GALAXIES ALONG THE WAY?

Mickey Haney
Redondo Beach, California

A: Determining the age of the Milky Way Galaxy is as difficult as determining the age of a forest: One can measure the ages of individual trees, but at what point in the past were there enough trees to define a forest? Similarly, we determine the age of the Milky Way by measuring the ages of stellar clusters and individual stars.

Mass dictates a star's lifetime. If stars form in a cluster, we can calculate the cluster's age by determining the most massive members remaining in the group. For the oldest globular clusters in the Milky Way, this method yields a maximum age of around 13.3 billion years, with an uncertainty of about ±2 billion years.

We also can estimate ages of individual stars, either by measuring the temperatures of stellar remnants called white dwarfs (they cool as they age) or the amount of radioactive elements in the atmospheres of long-lived low-mass stars. The oldest of both of these types of stars are about 12.6 to 13.2 billion years old. However, the stars that make up the main disk of the Milky Way appear to be younger — between 8 and 10 billion years.

So, the Milky Way clearly was — and is — a work in progress. We've observed dwarf galaxies currently being torn apart by, and merging with, the Milky Way, so it seems highly likely that this process was occurring in the past as well. Identifying which stars once belonged to what systems is a difficult, but not impossible, task.

Robert Benjamin
University of Wisconsin-Whitewater

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

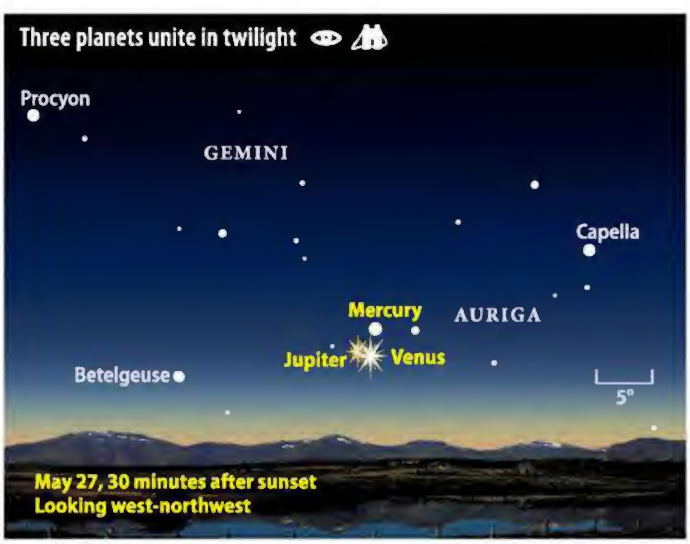
MARTIN RATCLIFFE and ALISTER LING describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

May 2013: Bright planets meet at dusk

Venus (upper left) and Jupiter appeared near each other at the end of January 2008. The two brightest planets should look equally spectacular in late May. MIKE SALWAY

Mercury, Venus, and Jupiter join together for a spectacular series of conjunctions in evening twilight. Brilliant Venus and striking Jupiter, in particular, will attract attention when they pair up during May's final week. Meanwhile, Saturn remains near its peak and dominates the overnight hours during late spring.



Venus and Jupiter stand side by side May 27, with Mercury glowing more dimly just above them. ASTRONOMY: ROEN KELLY

The early morning hours offer the return of Uranus and Neptune. You'll need binoculars or a telescope to find these distant worlds, which were lost in the Sun's glare for much of the winter and spring.

Three planets adorn late May's evening sky. We'll begin with the brightest, **Venus**, which is emerging in the west-northwest after its late March superior conjunction. Watch for the magnitude –3.9 planet just above the horizon starting in May's second week. Although it stands only a few degrees high 30 minutes after sunset, its visibility improves in the following weeks.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

You might be able to spot the crescent Moon on May 10, when our satellite slides 2° to the planet's lower left. The two appear 4° high a half-hour after sunset from mid-northern latitudes. You'll need binoculars to find the Moon, which is only 1 percent lit.

Jupiter then lies to the pair's upper left and nearly 20° high. A much thicker crescent Moon greets this planet two days later. Venus climbs to meet Jupiter in late May, but not before **Mercury** joins the show. The innermost planet comes into view after midmonth and passes 1.4° due north (upper right) of its sister world May 24. Mercury then glows at magnitude –0.9, three full magnitudes fainter than Venus. Jupiter, which shines at magnitude –1.9, lies a mere 4° to Venus' upper left.

This magnificent trio tightens even further in the next few days. All three lie within 2° of one another May 26 and 27. And on the 28th, Venus passes 1.0° north of Jupiter, creating a stunningly brilliant pair of jewels that lie only two Moon-widths apart. Mercury, which has faded slightly to magnitude –0.6, hangs 3° above them.

Following this series of conjunctions, Venus and Mercury continue to climb higher in the evening sky while Jupiter slides deeper into twilight. Mercury will reach its greatest elongation from the Sun on June 12, when it lies 24° east of our star and 4° from Venus.

When viewed through a telescope during May, Mercury and Venus appear distinctly different. Venus spans 10" and shows a nearly full

RISINGMOON

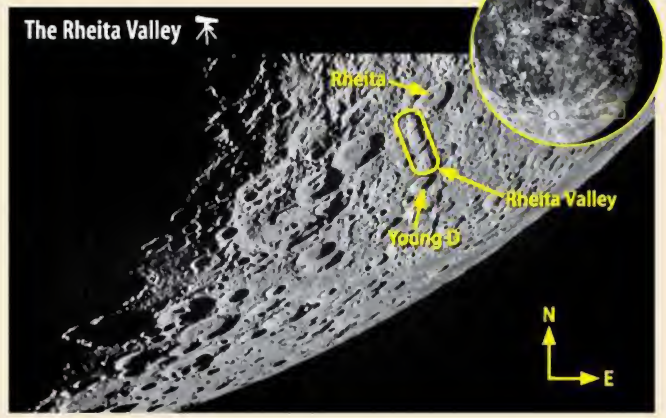
How drops of nectar built a huge valley

The most famous lunar valley is the Alpine Valley in the far north. But this month, let's focus on a worthy challenger: the Rheita Valley in the Moon's southeastern quadrant. Interestingly, the two valleys formed differently. The Alpine developed when the lunar crust pulled apart and the land between collapsed. The Rheita comprises a line of overlapping craters. The series of impactors that created it fell in rapid succession, which obliterated the central peak and rim of the crater formed just before it.

Such crater chains are common around most large young impact features, such as the crater Copernicus. The chains point radially away from the impact's center because the excavated material shot out in linear sprays. The Rheita Valley is the widest such chain, which implies that the original impact must have been huge. It was: It formed Mare Nectaris to the north.

With a bit of practice and an eye for detail, you can tell that the Rheita Valley is neither the freshest nor the oldest feature on this part of the Moon. Note a couple of chopped-off circles on the valley's northeastern flank. Their worn-down rims and floors testify to their creation prior to the valley. Rheita Crater at the valley's northeastern edge and Young D at the south end obviously arrived later because they appear sharper and have reshaped part of the valley.

Sunrise over Rheita Valley occurs May 13, but the view on the 14th more closely matches the image above. Take another look May 26 and 27, when the lighting is reversed under a setting Sun. This is when you can best see that the valley points directly back to Mare Nectaris.



A series of overlapping craters creates the Rheita Valley, the longest such feature on the Moon's nearside. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: LICK OBSERVATORY

phase, waning to 96 percent lit on the 31st. The illuminated portion of Mercury's 6"-diameter disk shrinks from 80 percent to 65 percent in the week following its May 24 conjunction with Venus.

Jupiter's low altitude hampers its telescopic appearance. Your best views will come in early May, when the gas giant spans 34" and should show some detail starting an hour or so after sunset. The planet's four bright moons remain easy to see all month.

Although **Saturn** reached opposition and peak visibility in late April, the view hardly deteriorates during May. Even better, the ringed planet stands higher in the evening sky and thus makes a more tempting target. At midmonth, it lies nearly 30° high in the southeast an hour after the Sun goes down and remains on view until morning twilight commences.

The ringed planet begins May among the background

— *Continued on page 42*

METEORWATCH

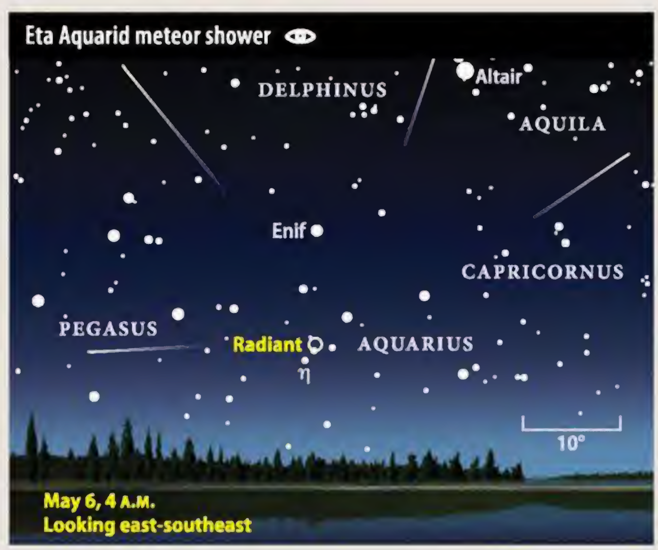
Happy trails courtesy of Comet Halley

Catching dust particles from Comet 1P/Halley isn't as hard as you might think. The European Space Agency's Giotto spacecraft managed the task during its 1986 encounter. And this month, Earth will sweep up many more during the annual Eta Aquarid meteor shower. These particles lie nowhere near Halley, which currently resides in the outer solar system, but instead fill the comet's orbit.

The shower peaks the night of May 5/6, when Earth runs into the densest part of this debris stream. The meteors appear to radiate from a point in Aquarius that rises shortly before 3 A.M. local daylight time. This offers an hour or two of observing before twilight starts to interfere. Fortunately, the Moon doesn't rise until around 4 A.M. For residents at mid-northern latitudes, the low radiant reduces the meteor count to about one-third the maximum rate of 55 meteors per hour.

Eta Aquarid meteors

Active Dates: April 19–May 28
Peak: May 5/6
Moon at peak: Waning crescent
Maximum rate at peak: 55 meteors/hour



Moon-free skies reign before morning twilight begins at the May 6 peak of the Eta Aquarid meteor shower. *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT Mercury, Venus, and Jupiter remain within 5° of one another in the early evening sky from May 24 to 29.

STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth

STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless magnified

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

MAY 2013

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

2 Last Quarter Moon occurs at 7:14 A.M. EDT

4 The Moon passes 6° north of Neptune, 3 A.M. EDT

SPECIAL OBSERVING DATE

5/6 The Eta Aquarid meteor shower peaks under a waning crescent Moon, making it one of only two major showers this year that avoid significant moonlight.

6 The Moon passes 4° north of Uranus, 8 P.M. EDT

9 New Moon occurs at 8:28 P.M. EDT; annular solar eclipse

10 Asteroid Pallas is in conjunction with the Sun, 5 P.M. EDT

11 Mercury is in superior conjunction, 5 P.M. EDT

12 The Moon passes 3° south of Jupiter, 9 A.M. EDT

13 The Moon is at apogee (252,168 miles from Earth), 9:32 A.M. EDT

18 First Quarter Moon occurs at 12:35 A.M. EDT

18 Venus passes 6° north of Aldebaran, 6 A.M. EDT

20 Mercury passes 7° north of Aldebaran, 9 P.M. EDT

22 The Moon passes 0.005° north of Spica, 7 A.M. EDT

23 The Moon passes 4° south of Saturn, 6 A.M. EDT

Asteroid Hebe is at opposition, 3 P.M. EDT

24 Mercury passes 1.4° north of Venus, midnight EDT

25 Full Moon occurs at 12:25 A.M. EDT; penumbral lunar eclipse

The Moon is at perigee (222,685 miles from Earth), 9:43 P.M. EDT

27 Mercury passes 2° north of Jupiter, 6 A.M. EDT

28 Venus passes 1.0° north of Jupiter, 5 P.M. EDT

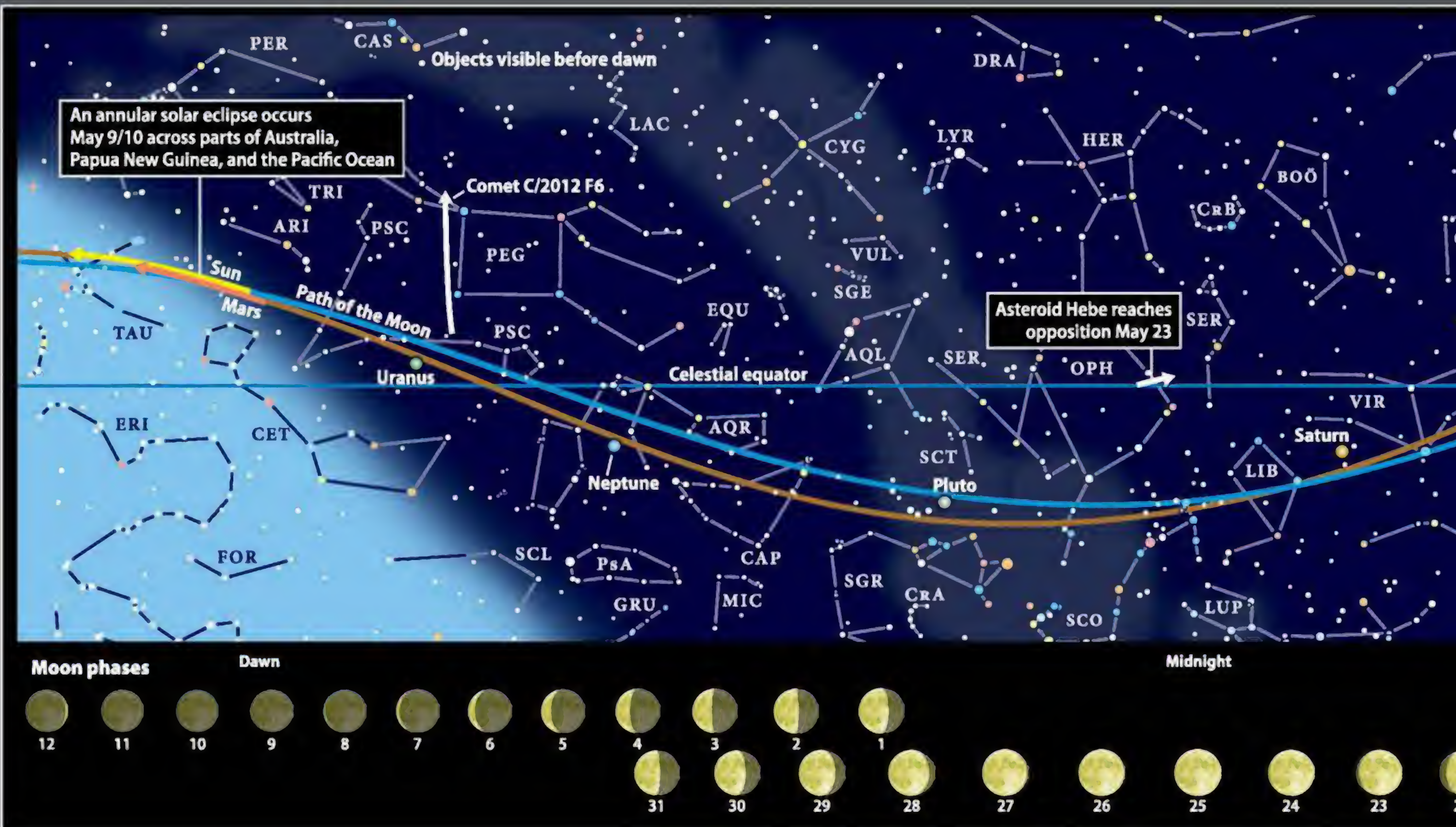
31 The Moon passes 6° north of Neptune, 10 A.M. EDT

Last Quarter Moon occurs at 2:58 P.M. EDT

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT www.Astronomy.com/starchart.

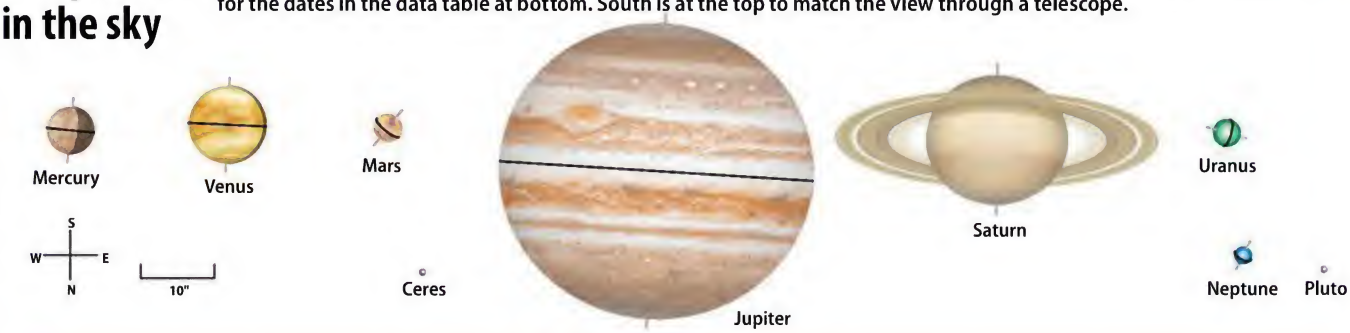
PATH OF THE PLANETS

The planets in May 2013



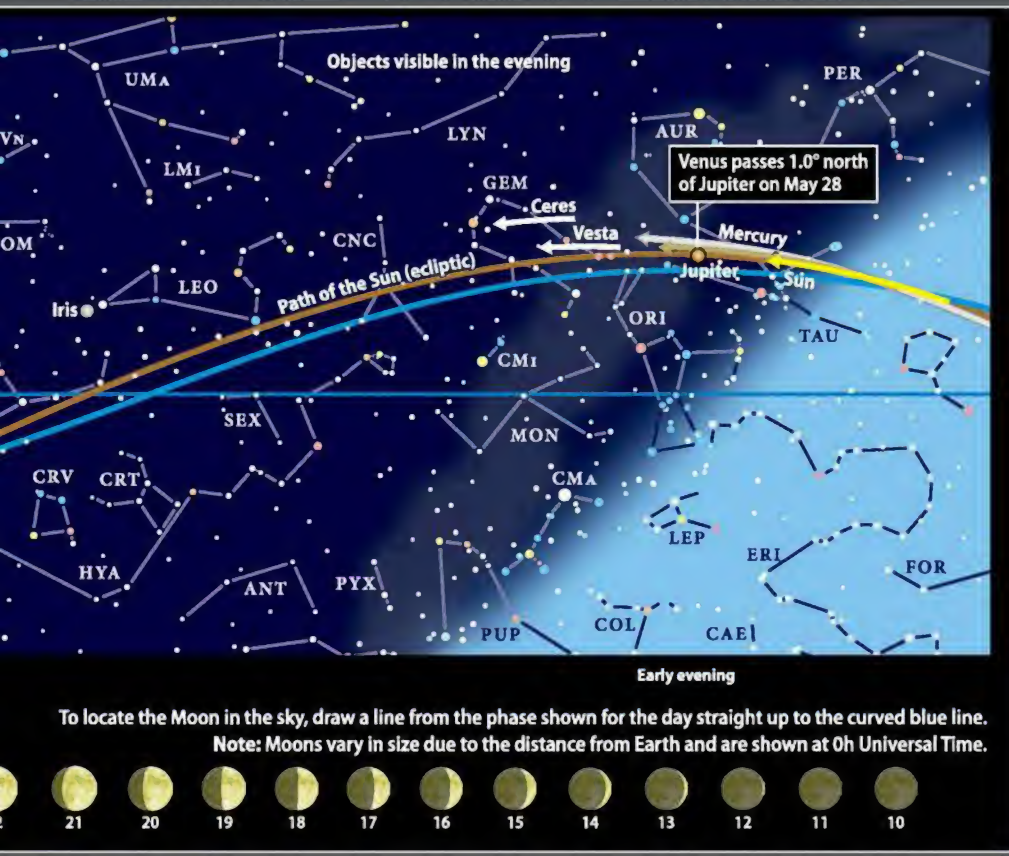
The planets in the sky

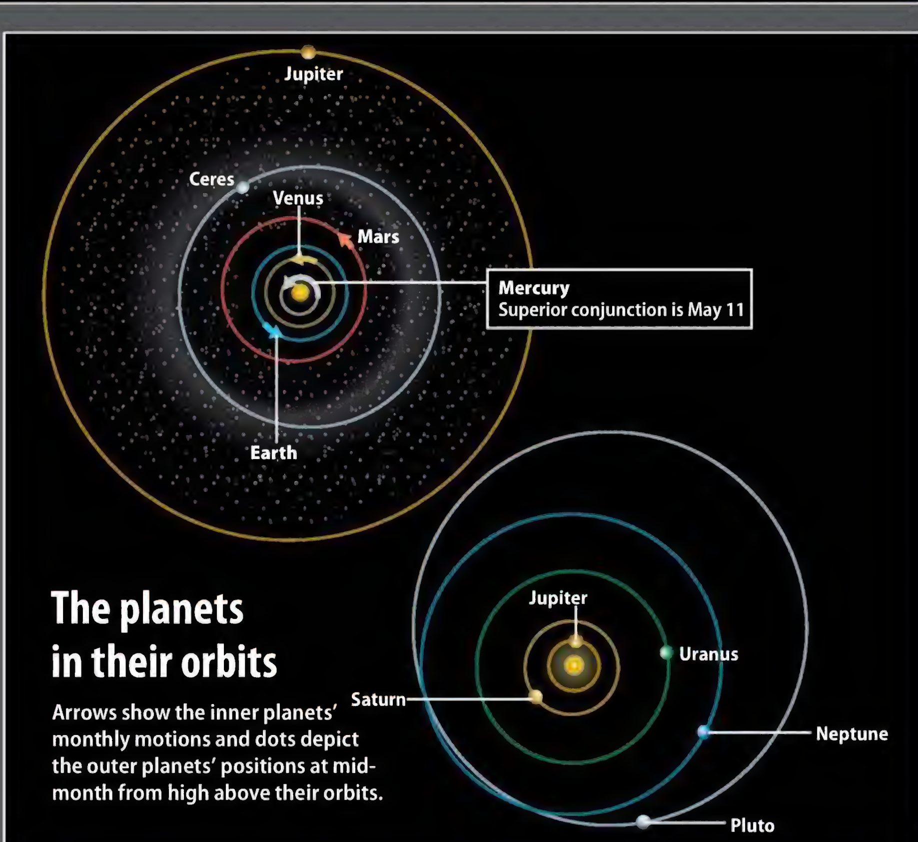
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	May 31	May 31	May 15	May 15	May 15	May 15	May 15	May 15	May 15
Magnitude	–0.5	–3.9	1.3	8.8	–1.9	0.2	5.9	7.9	14.1
Angular size	6.3"	10.2"	3.8"	0.4"	32.9"	18.8"	3.4"	2.3"	0.1"
Illumination	65%	96%	100%	98%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.064	1.630	2.459	3.114	5.996	8.858	20.773	30.161	31.740
Distance (AU) from Sun	0.363	0.719	1.458	2.583	5.108	9.826	20.050	29.986	32.437
Right ascension (2000.0)	5h57.0m	5h42.6m	3h02.1m	7h03.1m	5h17.8m	14h21.4m	0h40.7m	22h28.4m	18h47.3m
Declination (2000.0)	25°38'	24°12'	17°04'	28°29'	22°48'	–11°16'	3°39'	–10°16'	–19°42'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



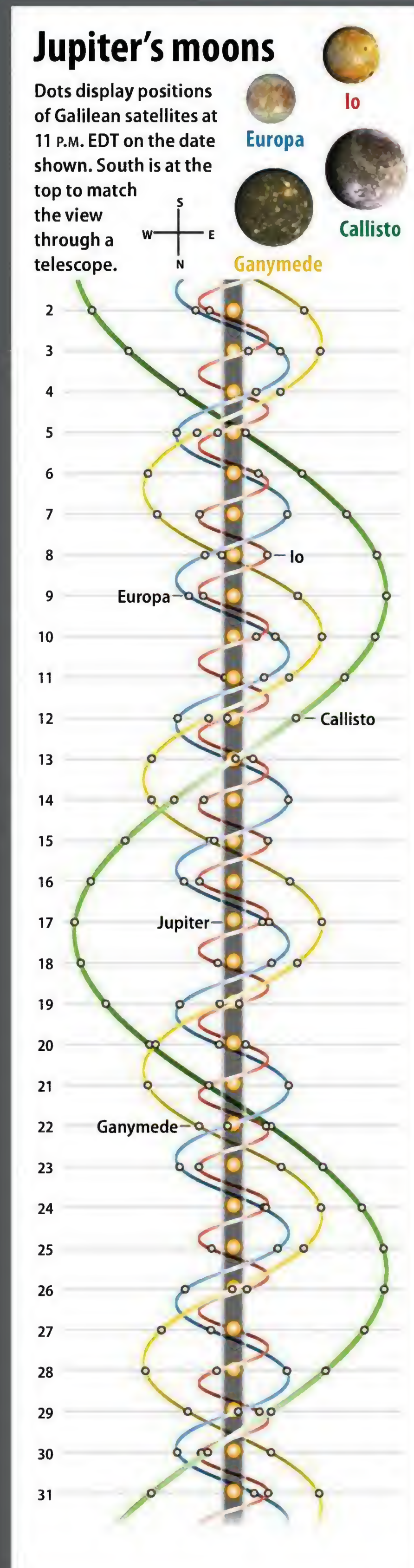


The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

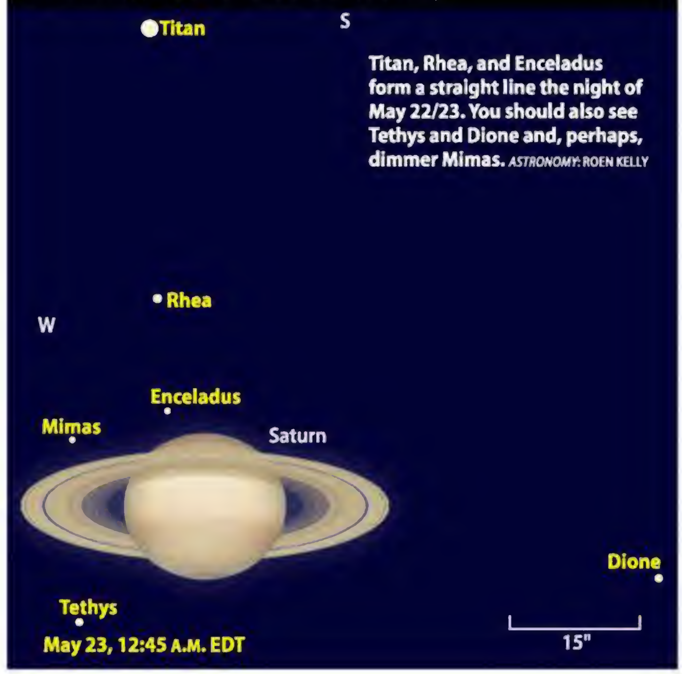
EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (northwest)	Saturn (south)	Saturn (west)
Venus (northwest)		Uranus (east)
Jupiter (west)		Neptune (southeast)
Saturn (southeast)		

stars of Libra and crosses into Virgo on the 13th. As Saturn continues along this retrograde (westward) path, it pushes within 2° of 4th-magnitude Kappa (κ) Virginis by month's end. The planet shines at magnitude 0.2 in mid-May, noticeably brighter than any nearby star. It easily beats Virgo's luminary, 1st-magnitude Spica, which lies nearly 15° west of Saturn.

When viewed through a telescope, the ringed world certainly lives up to its nickname. At first glance, it's easy to overlook the planet itself. But take a few minutes to examine the globe, which measures 19" across the equator and 17" through the poles. This flattening is easy to see once you know to look for it.

Next, shift your gaze to the rings. They span 43" and tilt 18° to our line of sight in mid-May — a gorgeous scene through any telescope. Even under mediocre observing conditions, you should see the broad Cassini Division that separates the planet's two brightest rings.

Watch three moons line up south of Saturn



Titan, Rhea, and Enceladus form a straight line the night of May 22/23. You should also see Tethys and Dione and, perhaps, dimmer Mimas. *ASTRONOMY:* ROEN KELLY

Several saturnian moons also show up through small telescopes. The brightest is Titan, the second-largest moon in the solar system, which glows at 8th magnitude and orbits Saturn in 16 days. You can find it north of Saturn on May 14/15

COMETSEARCH

The comet that never sets

The comet that charmed us in March and April remains within easy reach until mid-May as it fades on its outbound journey to the distant Oort Cloud. C/2011 L4 (PANSTARRS) should be easy to spot through binoculars from a dark site or with a small telescope from the suburbs. By summertime, however, you'll need bigger scopes and a dark sky to track its retreat. Fortunately, the comet slides through the Little Dipper in Ursa Minor this month, which means it stays visible all night for Northern Hemisphere observers.

The easiest way to follow its 7th-magnitude glow is to jump from 3rd-magnitude Gamma (γ) Cephei, known to many stargazers as the "top of the house" in the crude outline of Cepheus. It is the only bright star between Cassiopeia and Polaris. You won't have to move at all May 12 and 13 because PANSTARRS lies in the same field as Gamma.

Start observing the comet at low power to gauge the tail's extent. Gently tap the scope to allow your motion-sensitive night vision to pick up the low-contrast streak. Boost the magnification past 100x to examine the structure closely. The bright head, or coma, appears sharper on its southern edge where solar radiation pushes back on recently released dust. The coma likely will be brightest in the middle at the "false nucleus," the dense dust shroud that hides the true surface from sight.

On the nights of May 27 and 28, PANSTARRS tilts edge-on to our line of sight. Think of a flashlight's narrow beam seen from the side. Look for the comet before the waning gibbous Moon rises shortly before midnight. PANSTARRS then appears just a few degrees from Polaris and the modest star cluster NGC 188. Astronomers consider this open cluster to be one of the oldest in the galaxy.

Comet C/2011 L4 (PANSTARRS)

Although spring's best comet should fade below naked-eye visibility this month, C/2011 L4 (PANSTARRS) remains a treat with optical aid near the bright star Polaris. *ASTRONOMY:* ROEN KELLY

The May 9/10 solar eclipse will reduce the Sun to a ring of fire along a narrow central path in parts of Australia and the Pacific Ocean. Residents of Hawaii will see a still-impressive partial eclipse. RUBEN KIER

and 30/31, and south of the planet May 6/7 and 22/23.

Take notice May 22/23, when 10th-magnitude Rhea and 12th-magnitude Enceladus join Titan in a straight line south of the planet. Two other 10th-magnitude moons, Tethys and Dione, show up north and east of Saturn, respectively. The alignment will be worth viewing even though Earth's Moon shines brightly only 5° from Saturn.

Two-faced Iapetus grows significantly brighter during May. It stands southeast of Saturn on May 1 and moves slowly westward throughout the month. The moon appears 2' south of the planet May 9 and 10 as it heads toward greatest western elongation May 29/30. As it moves westward, it brightens significantly as its ice-covered hemisphere points more directly toward Earth. At greatest elongation, it shines at 10th magnitude.

By late May, both Neptune and Uranus rise well before twilight paints the predawn sky. **Neptune** pokes above the horizon by 2 A.M. local daylight time on the 31st, surrounded by the stars of Aquarius. That morning, the most distant major planet appears 6° south of the Last Quarter Moon. The 8th-magnitude world lies in the same binocular field as 5th-magnitude Sigma (σ) Aquarii.

Uranus rises around 3 A.M. local daylight time against the backdrop of Pisces. Late May is the best time to search for this 6th-magnitude world, which appears some 10° above the eastern horizon as twilight begins. Its low altitude and dimness will make it a challenge to see unless you have a clear, dark sky. The planet lies 4° south-southwest of the 4th-magnitude star Delta (δ) Piscium.

The May 9/10 New Moon passes directly in front of the Sun for residents along a path that stretches across northern Australia, Papua New Guinea, the Solomon Islands, and the Pacific Ocean. Because the Moon is near the far point in its orbit around Earth, this geometry creates an **annular solar eclipse**, and viewers will see a ring of sunlight around the Moon. (Be sure to view with a safe solar filter.) Observers on the center line in Queensland, Australia, will witness more than four minutes of annularity.

People in Hawaii will experience a partial eclipse of the Sun. Those on the southern coast of the Big Island will see 50 percent of the Sun blocked at 3:52 P.M. HST May 9. Honolulu residents will find 44 percent of the Sun covered at 3:48 P.M. HST.

An essentially undetectable **penumbral lunar eclipse** occurs May 24/25, when 1.6 percent of the Full Moon dips into the fringe of Earth's outer shadow. The eclipse begins at 11:53 P.M. EDT and lasts 34 minutes.

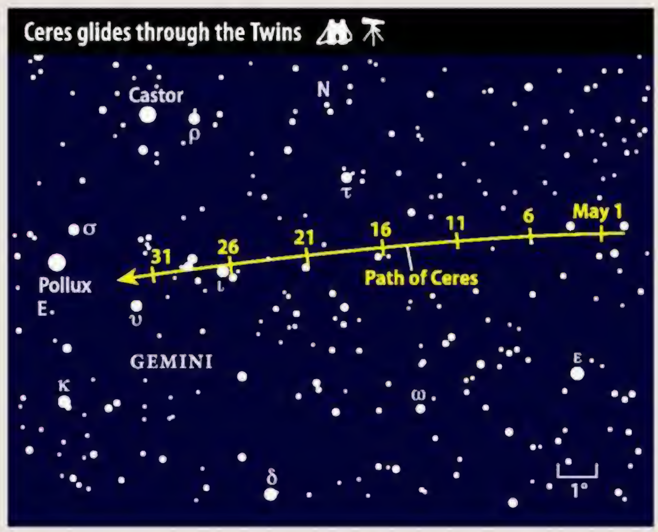
LOCATING**ASTEROIDS**

Ceres becomes a springtime gem

If you want to locate the king of the asteroid belt quickly, wait until the end of May. By then, 1 Ceres has exited the Milky Way's dense star fields and passes through a field of bright guide stars near 1st-magnitude Pollux. The simplest way to find it is to locate 4th-magnitude Iota (ι) Geminorum and then nudge your scope to the spot shown on the chart below for the particular night. The pattern of plotted stars should be recognizable through the eyepiece, with the odd man out being the 9th-magnitude asteroid.

If you need an asteroid fix early this month, you must accept a challenge. The rich starry background of our galaxy in western Gemini is like an orchard where every tree looks pretty much alike. There are precious few stars that stand out. Even if you use a go-to scope, the chances are you will face three or four stars of similar brightness. Make a quick sketch and return the next night to see which dot moved.

Sometimes there's another way to tell the difference between Ceres and a star of similar brightness. Stars twinkle in turbulent air, but planets do not (in short because they appear to cover more sky). Asteroids experience this non-twinkling effect, too, but more subtly. Experienced observers also note that larger asteroids such as Ceres appear flat compared with the sharper stars. Pump up the magnification and give it a try.



The largest asteroid cuts across Gemini in May, passing less than 1° from 4th-magnitude Iota (ι) Gem late in the month. *ASTRONOMY*: ROEN KELLY

GET DAILY UPDATES ON YOUR NIGHT SKY AT www.Astronomy.com/skythisweek.

The science behind UFOs

When an unidentified object appears in the sky, witnesses sometimes scramble to report a flying saucer. But even the strangest sightings have astronomical or technological explanations. **by Philip Plait**

It was crisp that late night in February 1997 as my father and I wandered the banks of Florida's Indian River. We weren't alone: Thousands of people were with us, all waiting for the launch of the space shuttle *Discovery*. I had spent two years working on a camera packed up inside *Discovery* and was eager to see it safely on its way to the Hubble Space Telescope.

The mood was festive despite the hour and the chill, all of us chatting and enjoying ourselves as we watched the countdown clock tick to zero. But then, just before launch, we had a close encounter.

It started with lights on the horizon, not far from the shuttle launch complex. We saw several of them, seemingly in formation along a curved line, moving slowly toward our location.

"Planes?" I muttered to my dad, but then remembered the strict no-fly zone NASA enforced around the facility. The lights clearly were not stars, and they were moving relative to each other, so they couldn't be satellites or a solid body. Still, they were obviously traveling as a group.

Certainly, I never would have admitted to myself that they were … you know.

Then the noise wafted over us. An odd sound, clearly coming from the overhead objects — a repeated staccato noise, weird but familiar. My brain spun like a wheel in mud, trying to get traction. But just as the lights were directly above us and I could make out their shapes, the noise became clearer as well.

They were ducks. Quacking. We were hearing quacking. The lights around us were illuminating their bodies, and when the birds had been farther off, the powerful spotlights playing over the shuttle had lit them, making them appear as if they were emitting their own light.

We turned as they flew past us, on to whatever ducky destination they had planned, their quacks fading. We looked at each other and laughed, maybe just a tad too loudly. Relieved, we walked back to the car where the rest of our family was waiting for us to join them in watching *Discovery* thunder into space, taking with it a camera that would view the cosmos with cold, certain physics and logical mathematics.

JOHN CHUMACK (WIDE-FIELD); NSSDC (VENUS); NASA/JPL/UNIVERSITY OF ARIZONA (JUPITER)

Venus (brightest) and Jupiter (center top), seen here from Dayton, Ohio, are often reported as UFOs by those unfamiliar with the motions and positions of the planets. When these bodies appear near the horizon, they are subject to more atmospheric effects than objects more directly overhead, causing them to appear to change in color and brightness.

The harsh light of reality

I look back at that evening fondly, and not just because it started several years of fascinating Hubble observations. I also learned a valuable lesson.

I am an astronomer, a scientist, a skeptic, a hard-nosed realist. And for a moment — just a moment — I was fooled by ducks, wondering if just maybe I was seeing something unearthly. If that can happen to me, it can happen to anyone.

In my defense, I did not ever really think I was seeing an alien fleet. But those seconds of disorientation were unsettling. I have considerable experience looking at the night sky, so not knowing what I was witnessing was peculiar.

Imagine if I had been at a different location, somewhat farther away, where the sound was inaudible and the ducks looked like dots. Would I have been able to identify them as birds? Maybe. But it wouldn't have surprised me if someone else had reported a half-dozen unidentified flying objects (UFOs) dogging the shuttle launch. At least in this case we could easily turn them into identified flying objects (IFOs).

I AM AN ASTRONOMER, A SCIENTIST, A SKEPTIC, A HARD-NOSED REALIST. AND FOR A MOMENT — JUST A MOMENT — I WAS FOOLED BY DUCKS.

But we do see similar UFO reports all the time: lights, rapidly changing color, hovering or darting about, and observed by dozens or hundreds of witnesses. Almost every time, the actual culprit is something mundane (like waterfowl), observed with our imperfect sensory organs and filtered through our easily fooled brains.

Sometimes the explanation turns out to be forehead-slappingly obvious; sometimes it truly is unearthly — but not in the way witnesses thought. Regardless, it is fun to look into these reports and see what scientific and technological explanations are behind them.

◄ On February 25, 1942, UFOs near Los Angeles led to a military mobilization and a blackout. Before they reached the city, the UFOs disappeared. An hour later, anti-aircraft artillery enacted an air-raid reaction. Conflicting official statements about the targets' nature — Japanese planes, U.S. planes, stray weather balloons, or nothing — led to speculation about the potentially alien nature of the UFOs. Known as the Battle of Los Angeles, the event inspired this image of spotlights converging over the city. The question is, "Converging on what?"

LOS ANGELES TIMES (SPOTLIGHTS); ISTOCKPHOTO/THINKSTOCK (UFO); J. S. HENRARDI (BELGIUM TRIANGLE)

DATELINE
March 2010. Euclid, Ohio.

Dozens of people reported a UFO: a bright object on the western horizon, hovering over Lake Erie and nearby Cleveland. The light was intense and lasted for hours. Sometimes it moved, and other times it was stationary, but it returned to the same spot night after night.

The sight was featured in local news media, specifically the Fox network. A national MSNBC segment, hosted by David Shuster, highlighted the phenomenon after the lights reappeared nine nights in a row. Speculation abounded, including, of course, that the light was from an alien spaceship.

The thing is, this UFO really was alien. But it did not contain visitors from an alien world. It *was* an alien world — Venus. Here's how we know.

The suburb of Euclid is east of Lake Erie and northeast of Cleveland, and in March of that year, Venus set in the west — the direction in which people saw the "UFO." The planet also tends to be in similar spots night after night, which explains why the UFO returned repeatedly. And it stands out: For people unfamiliar with it, Venus is

Releasing "sky lanterns" has become a common celebratory practice. In this image, photographed from below, it's easy to see how the objects could appear otherworldly from the perspective of someone unaware of the event. ISTOCKPHOTO/THINKSTOCK

shockingly brilliant — it is the third-brightest natural object in the sky, after the Sun and Moon.

As the sky darkens after sunset, Venus becomes easier to see. One moment it is not there, and the next — bang! It's obvious. It is often low on the horizon, and seen through our turbulent atmosphere, the planet appears to dance and change colors, or "scintillate." This same effect makes stars twinkle. Like a prism, the atmosphere can refract light, breaking it up into colors, and Venus can rapidly flash between red, green, and yellow, before going back to white.

But what about the UFO's movement? Well, there's a human perception phenomenon called "autokinesis": Small motions of the head and eye can make a bright spot appear to flit back and forth if it is in front of a dark background — like Venus and the night sky. In 1799, Prussian geographer Alexander von Humbolt first recorded the effect, which he thought revealed the actual movement of stars. Fifty-eight years later, Swiss psychologist Gottfried Schweitzer discovered that the phenomenon was actually all in people's heads.

There is one last nail in this UFO's coffin: Venus is bright and apparent in the sky. Isn't it curious, then, that none of the witnesses mentioned seeing the UFO *and* Venus? They wouldn't have — if the UFO were actually the planet.

While our neighbor Venus is a commonly reported UFO, other planets also confuse eyewitnesses.

UFO REPORTS BY STATE

State/Province	Percentage of total North American UFO reports
1. California	13.2
2. Washington	6.0
3. Florida	5.3
4. Texas	5.2
5. New York	4.5
6. Illinois	3.8
7. Arizona	3.6
8. Pennsylvania	3.4
9. Ohio	3.1
10. Michigan	2.9
11. Oregon	2.5
12. North Carolina	2.4
13. Missouri	2.2
14. Colorado	2.1
15. Ontario	2.1

Californians spot more UFOs than those in other parts of North America. Just 15 states and provinces account for 60.2 percent of reports.
SOURCE: NATIONAL UFO REPORTING CENTER

DATELINE
October 14, 2010. New York City.

Reports of UFOs came in all day to the New York City Police Department and the Federal Aviation Administration from witnesses seeing lights moving in formation and then fading from view.

Sensing a story, WNYW-TV sent a reporter to investigate. While interviewing eyewitnesses, she too saw a light in the sky. The correspondent continued to discuss what she saw, and the cameraman aimed and zoomed in on the UFO. In the news footage, the object resolves into five separate lights — a bright one surrounded by four smaller ones. What could it be?

Too bad Galileo Galilei was not walking the streets of the Big Apple on that autumn day. He could have told the reporter what she was seeing, since he first observed those lights back in 1610: Jupiter and its four moons.

There is no guesswork with this one; anyone who has looked at Jupiter through a telescope could watch the recording and confirm this was the gas giant and its largest satellites. To the eye, Jupiter just appears as a single bright "star," but with even small binoculars, you can see it as a disk attended by its four giant moons (which look like fainter, but still distinct, "stars" usually on either side of the planet). A good television camera, like the one WNYW-TV used that day, can easily separate the moons from Jupiter itself, making it appear as a miniature solar system. Though not as commonly reported as Venus — probably because it is dimmer and higher in the sky — Jupiter does make the rounds as a UFO imposter.

THE THING IS, THIS UFO REALLY WAS ALIEN. BUT IT DIDN'T CONTAIN VISITORS FROM AN ALIEN WORLD. IT *WAS* AN ALIEN WORLD — VENUS.

But a planet does not explain everything. The TV station investigated because of multiple separate UFO reports. They could not all have been Jupiter. Were these sightings real or just a bunch of hot air?

DATELINE
Earlier on October 14, 2010. New York City.

The sightings were real enough. Dozens, perhaps hundreds, of people saw silvery

Philip Plait *writes the blog* Bad Astronomy *on www.Slate.com. He is the author of* Bad Astronomy: Misconceptions and Misuses Revealed *(Wiley, 2002) and* Death from the Skies! These Are the Ways the World Will End *(Penguin, 2009).*

spots hovering or soaring slowly through the Manhattan sky.

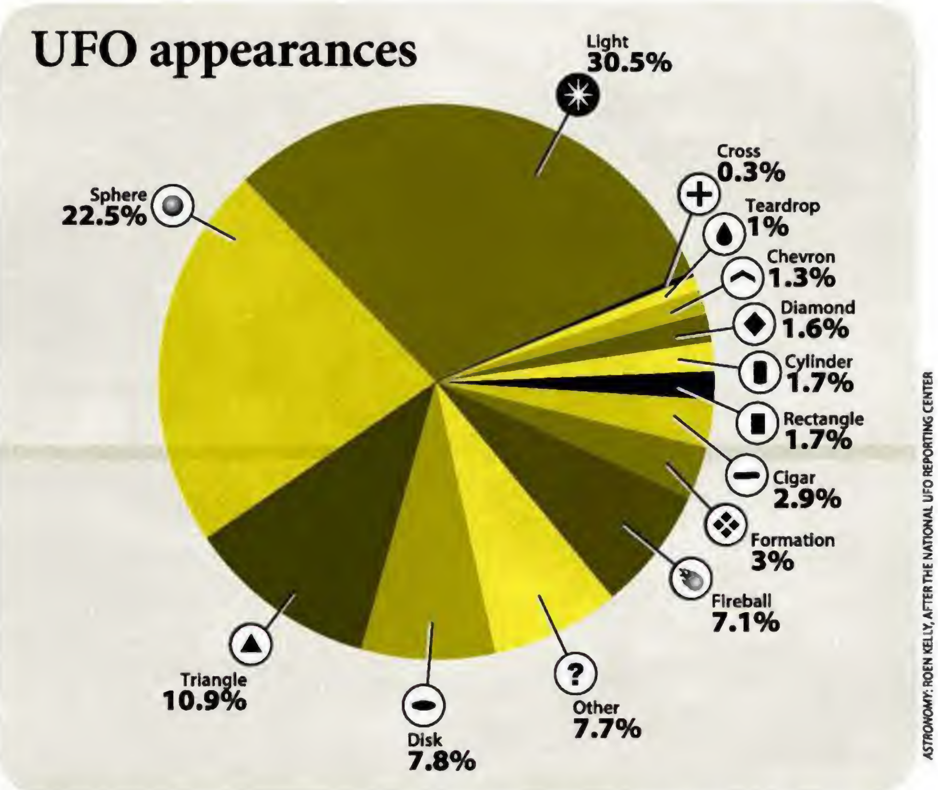
Once again, however, they were not alien craft. They were, in fact, just balloons from a marketing stunt: As part of an event encouraging tourism between the United States and Spain, a company gave away helium balloons, and the recipients released them in droves. When seen from a distance, with the Sun shining on them in the right way (like the ducks), they looked like solid metallic objects — spaceships.

Releasing objects that float away has become especially popular recently. Sending paper bags with candles suspended beneath them (creating a mini-hot air balloon known as a "sky lantern") into the air, for instance, is a popular wedding tradition. From far away, the balloons can resemble alien vessels because they emit light and move slowly, and many UFOs have been traced to nearby nuptials.

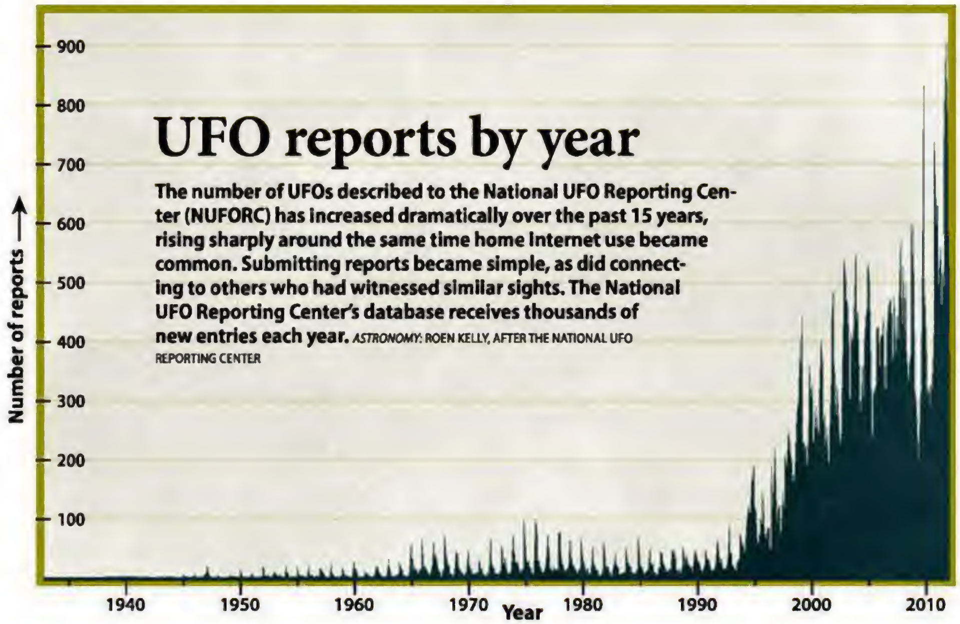
Sometimes, of course, there are also hoaxes of the inflatable kind. In January 2009, New Jersey residents Joe Rudy and Chris Russo released helium balloons with flares underneath to see how the media would react. The result was just as the two men desired: local and national coverage and prominent billing on the History Channel program *UFO Hunters*. The public was intrigued, especially after Rudy and Russo repeated the stunt four more times. They revealed the hoax April 1, 2009, by posting a written explanation of their reasoning and video evidence online.

During the debacle, local news stations interviewed a pilot, Paul Hurley, who claimed one of these objects buzzed his plane and then shot off to the side. Almost certainly, what Hurley saw was a balloon being caught by the wind and thrown near his aircraft.

Reporters often interview pilots as authoritative sources on UFOs under the assumption that because they watch the sky all the time, they cannot be fooled. But clearly they, and anyone who sees a pattern they do not expect, can. Sometimes pilots even wind up causing a UFO flap.



Of all UFOs described to the National UFO Reporting Center, these are the 14 most common shapes, by percentage. Spheres and lights tend to have straightforward, astronomical explanations.



The number of UFOs described to the National UFO Reporting Center (NUFORC) has increased dramatically over the past 15 years, rising sharply around the same time home Internet use became common. Submitting reports became simple, as did connecting to others who had witnessed similar sights. The National UFO Reporting Center's database receives thousands of new entries each year. ASTRONOMY: ROEN KELLY, AFTER THE NATIONAL UFO REPORTING CENTER

DATELINE
March 13, 1997. Phoenix.

Thousands of people reported mysterious lights flying together across Nevada and Arizona. Some witnesses saw a V-shaped craft passing over a large swath of Arizona, while those near Phoenix saw lights hovering above the city and winking out as if accelerating to warp speed. Abundant picture and video records exist, mostly of the second sighting, but the visual evidence combined with conflation of two events helped make the bizarre "Phoenix Lights" a national sensation, with documentaries, books, and websites devoted to them.

The first event was likely jets flying in formation. The human eye and brain connect dots when there are no physical links between them, making discrete objects look as if they are attached together by something solid when they are seen against a contrasting background.

For the hovering lights, the explanation is definitive: Air National Guard flights from Luke Air Force Base in Glendale, Arizona, sent LUU-2B/B flares parachuting as part of a routine test. As the flares fell behind mountains, they disappeared from view, or "winked out." Many witnesses saw the planes, and Lieutenant Colonel Ed

UFOS: A TIMELINE

The first photographic evidence of a UFO came in 1883, when Mexican astronomer Jose Bonilla saw 300 objects flying in front of the Sun while he was researching sunspots at Zacatecas Observatory in Mexico. Recent research by another Mexican astronomer, Hector Manterola, suggests that the mysterious objects were actually pieces of a fractured comet. Since Bonilla's observation, witnesses have reported thousands of UFOs. Here are images of some of the most famous, ranging from the traditional "flying saucer" to more Space Age appearances.

McMinnville, Oregon (1950). PAUL TRENT

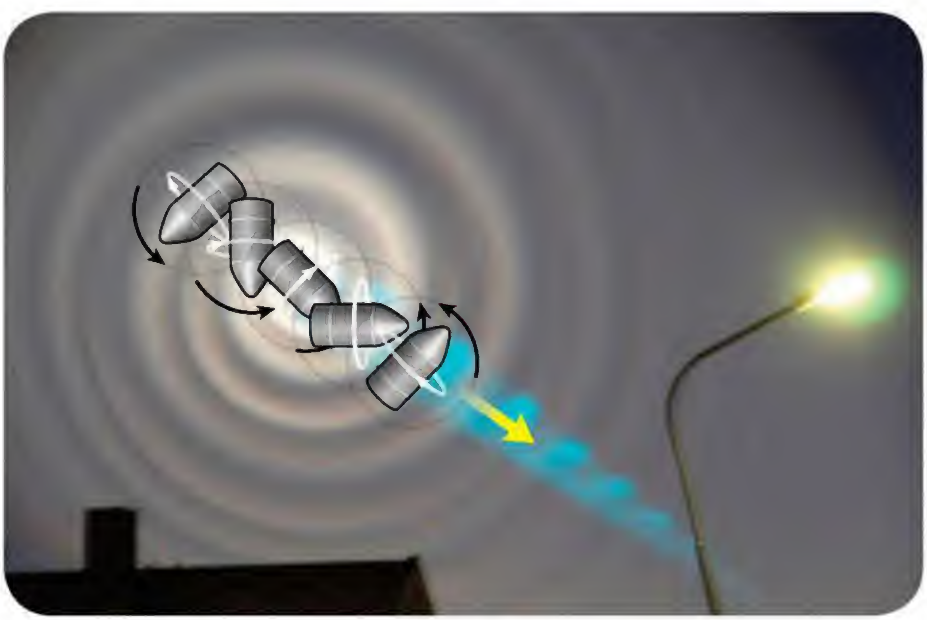
Cave Junction, Oregon (1927). UFO CASEBOOK

Redbud, Illinois (1950). DEAN MORGAN/UFO CASEBOOK

Passaic, New Jersey (1952). GEORGE STOCK/ UFO CASEBOOK

Jones, a National Guard pilot who flew one, testified he had dropped flares that night. The evidence for an earthly explanation adds up, and the mystery of the Phoenix Lights is solved.

Lights are the most commonly reported UFOs and the easiest to explain. When UFOs are more exotic, though, the physical mechanisms behind their appearances can be more complicated.



Two consecutive fuel leaks in a Russian Bulava missile caused these coiling formations in the sky above northern Norway. After it was above the atmosphere, the booster suffered two ruptures and began to spin and spray fuel, forming these spirals much like a sprinkler does with water. *ASTRONOMY*: ROEN KELLY (ILLUSTRATION); ODD MAGNE HAUGEN/ALTAPOSTEN (BACKGROUND)

DATELINE
December 9, 2009. Norway.

The people of Norway woke up to a most bizarre show: a gigantic, shining, spinning white spiral in the sky, like a huge cosmic pinwheel, with a tighter, longer, bluer coil pointing right at its heart.

People watched in awe as the spiral moved across the sky. Then, after a few seconds, a black circle appeared in its center and expanded, gradually erasing the spiral from the inside out. Moments later, the apparition was gone.

When I saw the pictures and video from this event, for several seconds I was seriously freaked out. Of course, within hours the Web was alight with speculation, claiming everything from "an alien spaceship" to "an unstable transdimensional vortex eaten by its own black hole." Although I put little stock in those explanations, the truth is still fascinating and surprising: In this case, a spaceship really did cause the phenomenon.

The Russian government admitted to launching a projectile from a submarine 26 hours before the spiral appeared and said its third stage had failed. Space historian

Washington, D.C. (1952). UFO CASEBOOK

Italy (1960). UFO CASEBOOK

Wallonia, Belgium (1990). J.S. HENRARDI

and *Astronomy* contributor James Oberg wrote an article in the January 19, 2009, *IEEE Spectrum* explaining how the anomaly could have resulted from a failed Bulava missile test.

The coiling formation was due to, of all things, a fuel leak. Imagine a garden sprinkler with a nozzle that spins horizontally. Seen from above, the water looks like it is ejected in a spiral, but that is actually an illusion. Each drop shoots straight away from the nozzle, but the head's rotation means each successive drop leaves in a slightly different direction, forming the observed spiral pattern.

The Russian booster was well above the atmosphere when, still loaded with propellant, it suffered a major leak and started to spin rapidly, spewing fuel into space like a huge, flammable sprinkler. The smaller blue coil formed first from a rupture, and moments later a second, bigger leak caused the larger white swirl. The ejected fuel continuously created spiral arms that expanded outward. When the fuel tanks were empty, the arms disappeared from the inside out, causing the dark circle in the center to form and grow. You can see the same principle in action when you turn off the water feed to a sprinkler.

Since this event, witnesses have seen two more such spirals from rocket failures: one again over Norway (a Russian Topol missile) and the other over Australia (SpaceX's Falcon 9 launch system).

WHEN I SAW THE PICTURES AND VIDEO FROM THIS EVENT, FOR SEVERAL SECONDS I WAS SERIOUSLY FREAKED OUT.

Ironically, in the end, these spirals are evidence of intelligent life traveling through space. But that life is us.

Turning a U into an I

All of these sightings have one thing in common: They are misidentified flying objects (MFOs?). Venus, Jupiter, balloons, flares, airplanes, and even rockets seem like things you would know when you saw them, but that turns out not to be the case. People even have reported the Moon as a UFO. When you are not expecting to see them, even ordinary things can appear to be extraordinary.

Worse, most people simply are not familiar with what is going on in the sky. They are surprised to learn that planets and satellites are visible from the ground. And the reason for that is simple: People do not look up.

Looking up is the simplest way to learn about the sky. A lot of amazing things are happening literally right above our heads. To be honest, I am happy people report all these "UFOs" because it means they are paying attention. It's a good first step. The all-important second step is turning UFOs into IFOs. That effort has the best reward of all: understanding.

Comprehension adds to the wonder of what we observe. We have the whole universe laid out before us, and to start understanding it, all we really have to do is look up.

FIND MORE OF PHILIP PLAIT'S IN-DEPTH UFO DEBUNKINGS AT **www.Astronomy.com/toc.**

Target Hubble's galaxy classes

How do astronomers classify galaxies? Find out by observing the various types. **by Alan Goldstein**

If you are familiar with spiral, elliptical, and irregular galaxies, you have Edwin Hubble to thank. It was he who was instrumental in expanding the universe beyond our Milky Way.

No, he didn't do it single-handedly; Heber D. Curtis and others were involved in the observations of novae and supernovae in nearby galaxies. In 1923, a time when most astronomers thought all star systems belonged to the Milky Way, Hubble determined the light curve of a special type of variable star in the Andromeda Galaxy (M31). A year later, galaxies were largely viewed as "beyond the Milky Way."

Sorting through galaxies

One of Hubble's greatest contributions was determining the relationship between how fast a galaxy is moving away from us and its distance (a quantity now known as the Hubble constant). But he also investigated the nature of galaxies and asked himself if there was an organization to them. In 1936, he defined a classification system in his book *The Realm of the Nebulae*.

He created a diagram in the shape of a simple tuning fork. Elliptical galaxies from round to highly elongated sit at one end. At the other end are the fork's two tines: regular and barred spirals. The lenticular galaxies, which have characteristics of both types, mark the intersection point. Finally, Hubble called any system not represented an irregular galaxy.

Astronomers (including Hubble) understood that a classification scheme could not be rigid. Many galaxies fit between the simple types. So, transitions exist between the three main types of spirals, between normal and barred spirals, and between lenticulars and spirals.

Hubble died in 1953. In 1961, another American astronomer, Allan Sandage, revised Hubble's system and published *The Hubble Atlas of Galaxies*.

Sandage included numerous photos in the book taken through Mount Wilson Observatory's 60-inch and 100-inch telescopes as well as the 200-inch Hale Telescope atop Palomar Mountain.

NGC 205 is a satellite of the more-famous Andromeda Galaxy (M31). Although this galaxy is elliptical, it is far from spherical. ANTHONY AYIOMAMITIS

The lenticular galaxy called the Ghost of Mirach (NGC 404, upper right) lies less than 7' north-northwest of magnitude 2.0 Mirach (Beta [β] Andromedae). To see it well, place the star outside your eyepiece's field of view. ANTHONY AYIOMAMITIS

Note that those instruments were state of the art. Today, however, amateur astronomers using CCD cameras regularly take images of comparable quality with mirrors a fraction of the size of those giants.

What the types show

Those of us who enjoy observing galaxies are prone to create lists of targets, and one of the easiest is a list that spans the Hubble classification. Although many of these galaxies show up through small telescopes, aperture counts, so if you want to view them, use the largest instrument you can.

As far as the types Hubble defined, elliptical galaxies contain mainly older stars.

Alan Goldstein *has created observing lists since 1973. He now skygazes from Louisville, Kentucky.*

Sb spiral Bode's Galaxy (M81, right) and the irregular known as the Cigar Galaxy (M82) lie only 0.6° apart in Ursa Major. A wide-angle view offers a great contrast between these two Hubble classifications. M81 is brighter, but M82 is just as easy to see because of its higher surface brightness. JASE JENNINGS

They lack the dust and gas clouds necessary for star formation. Their shapes increase in ellipticity from E0 (round) to E7 (spindle-shaped). And while anyone can note an elliptical's overall figure, the subtle differences between E0 and E1 or E6 and E7 may be lost on a beginning observer.

Lenticular galaxies (Hubble designated them as S0) have stellar populations similar to ellipticals but also have flattened disks like spirals. Hubble divided S0s into early, middle, and late types, designating them $S0_1$, $S0_2$, and $S0_3$, respectively. Early types closely resemble ellipticals while late types share more characteristics with normal spirals. Barred lenticulars ($SB0_1$, $SB0_2$, and $SB0_3$) also exist.

Through the eyepiece, the subtleties between early and late types of galaxies are not usually visible. Many of the differences depend on the object's orientation. Except for the closest galaxies, the details that make them different usually show up only on images. "Subtle" is the operative word here.

Normal and barred spiral galaxies are the most fascinating, but they also can be the most disappointing or frustrating for beginners. They contain populations of

NGC 1300 is a classic barred spiral galaxy that has the shape of a squashed letter S. To find it, look 2.3° due north of magnitude 3.7 Tau⁴ (τ^4) Eridani. R. JAY GaBANY

Barred lenticular NGC 2859 in Leo Minor dominates a rich field of galaxies. In this image, NGC 2859 is the largest and brightest galaxy and lies to the right of center. BERNHARD HUBL

bright young stars mixed with dust and gas. The round central hubs (which look oval if the galaxy is not face-on) dominate the disks in some types, are quite small in other types, and are virtually nonexistent in still others. Barred spirals have a highly elongated hub. Unfortunately, only the brightest and closest galaxies show spiral arms through average amateur telescopes.

A few galaxies share traits of both types of spirals. This proves once again that the universe doesn't work with a rigid classification system.

Observing tips

Whenever I can, I focus on the archetype galaxies — those that fit as close to Hubble's "normal" classification as possible. I also choose those that show the most structure through modest apertures. Here are seven guidelines for maximizing what you see.

1) Observe at a dark site during nights with good seeing (atmospheric stability). No galaxy trumps light pollution. Spirals are especially vulnerable to scattered light because the glare will hide the luminous disk, although the hub may shine through.

2) Don't start with spirals until your eyes fully adjust to the darkness. The difference between seeing a disk and a spiral arm may be a few extra dark-adapted rods in the back of your eye.

3) Face-on spirals require the darkest skies possible because you are observing through the thin plane that marks the disk.

4) The hub-to-disk ratio of spirals is easiest to estimate when you view edge-on or face-on spirals. Unfortunately, most orientations fall somewhere between these two extremes.

5) Revisit old friends. With experience, you will see detail you missed before, even if sky conditions and the telescope you observe with remain constant.

6) Start with the brightest galaxies, then work toward dimmer ones.

7) Check your optics regularly for dew.

The ellipticals

M87 (Hubble class E1): Located in the heart of the Virgo cluster, M87 is elliptical in classification, but which one? Hubble listed it as a peculiar E0, but some astronomers have since moved it to E1, proving that even with seemingly simple galaxies, the classification remains subjective.

A bright nucleus associated with a supermassive black hole in M87's core is visible through most telescopes. It's even bright enough to be visible through some binoculars. Through telescope/eyepiece combinations that have a bit more than a 1° field of view, M87 looks like a floating orb with M86 and NGC 4438 in the same field.

M86 (Hubble class E3): A neighbor of M87, this galaxy is obviously not round — even through a small telescope. Like many ellipticals, little additional detail is visible through larger apertures. What is impressive is the sheer number of stars visible within M87 and M86. Not many small-telescope views reveal two gargantuan galaxies so easily.

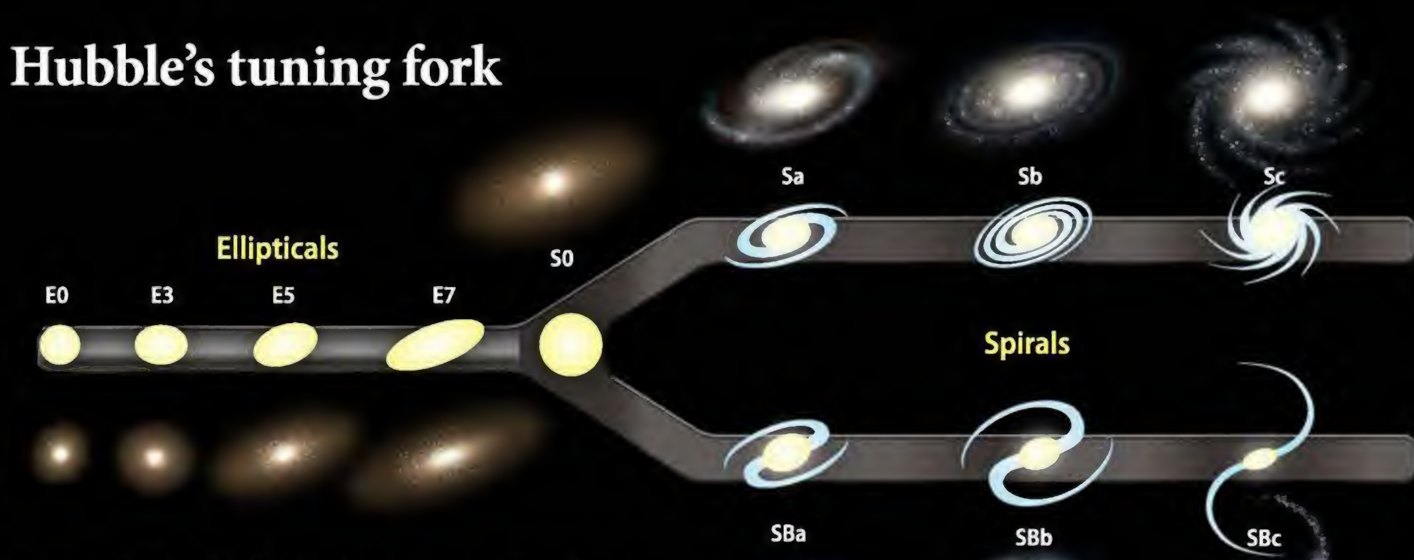
NGC 205 (Hubble class E5): Take a look toward the Andromeda Galaxy (M31) and spot its two satellites, M32 and NGC 205. Because they lie in the same field of view, the overall shape and variation of star density between this pair is evident. NGC

OBSERVE THESE GREAT GALAXIES

Object	Class	R.A.	Dec.	Mag.	Dimensions	Page
NGC 205	E5	0h40m	41°41'	8.1	19.5' by 12.5'	3
NGC 404	$S0_3$	1h09m	35°43'	10.3	6.1'	6
NGC 1300	SBb	3h20m	–19°25'	10.4	5.5' by 2.9'	45
NGC 2217	SBa	6h22m	–27°14'	10.7	5.0' by 4.5'	43
NGC 2859	$SB0_2$	9h24m	34°31'	10.9	4.6' by 4.1'	42
M81	Sb	9h56m	69°04'	6.9	24.0' by 13.0'	19
M82	Irr. Type 2	9h56m	69°41'	8.4	12.0' by 8.5'	41
NGC 3115	$S0_1$	10h05m	–7°43'	8.9	8.0' by 2.8'	1
NGC 4262	$SB0_{2/3}$	12h20m	14°53'	11.6	1.9' by 1.8'	42
M86	E3	12h26m	12°57'	8.9	12.0' by 9.3'	1
NGC 4449	Irr. Type 1	12h28m	44°06'	9.6	5.5' by 4.1'	40
M87	E1	12h31m	12°23'	8.6	7.1'	2
M104	Sa	12h40m	–11°37'	8.0	7.1' by 4.4'	24
NGC 4612	$SB0_1$	12h42m	7°19'	10.9	1.6' by 1.3'	42
M51	Sc	13h30m	47°12'	8.4	8.2' by 6.9'	31

Key: R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude; Page = The page the galaxy appears in *The Hubble Atlas of Galaxies*

Hubble's tuning fork



Astronomers have used the Hubble sequence, commonly known as the tuning fork model, to classify galaxy shapes for more than 75 years. Ellipticals are on the left, lenticulars (S0) fall in the middle, and both kinds of spiral galaxies appear on the right; this does not imply an evolution through time, however. (Irregular galaxies do not appear on the model.) *ASTRONOMY*: ROEN KELLY, AFTER NASA/ESA

205 is highly elongated and has a lower surface brightness. There are fewer stars in a given volume of space. Its compact core is visible through a 6-inch scope. Hubble listed it as a peculiar galaxy transitional to lenticular, although more recent galaxy lists classify it as E5.

One transition to lenticular example

NGC 3115 (Hubble class $S0_1$): Originally categorized as an E7, this object turns out to have more characteristics of a lenticular galaxy. Through small scopes, the spindle shape is quite evident. In large scopes, the best superlative is "spectacular!" It is edge-on, shaped like an American football, and bisected by a bright central axis.

Normal and barred lenticulars

The Ghost of Mirach (NGC 404; Hubble class $S0_3$): This is the nearest lenticular galaxy. It lies just beyond the Local Group, about 10 million light-years away. Hubble listed it as a late type because of a partial dust ring, a feature more common to normal spirals than ellipticals. NASA's Galaxy Evolution Explorer telescope discovered a ring of young stars from a collision with another galaxy, indicating it does indeed have the right classification. Telescopically, NGC 404 is in the same field as Mirach (Beta [β] Andromedae) but is bright enough to be visible despite the star's distracting glare. It appears as a small, round glow with a slightly brighter center.

NGC 4612 (Hubble class $SB0_1$): Located in Virgo, this is the only pure example of this galaxy classification in the atlas. It shines at magnitude 10.9 and measures a diminutive 1.6' by 1.3'. The bar is quite faint compared to those in $SB0_2$s and $SB0_3$s, and is a challenge to detect. A brighter example of this type (although not in *The Hubble Atlas*) is NGC 1023 in Perseus.

NGC 2859 (Hubble class $SB0_2$): This galaxy lies in Leo Minor, though it sits in the same field of view as magnitude 3.1 Alpha (α) Lyncis. Here is one of the best examples of a mid-to-late type SB0. It is relatively bright (magnitude 10.9) but, except for the nuclear region, also relatively featureless when viewed through small telescopes. Larger scopes will show a faint ring surrounding a brighter inner circle.

LEARN **MORE**

Many other telescope-friendly lists of galaxies exist, including seasonal ones. To purchase a PDF package of *Astronomy* articles about galaxy observing, visit **www.Astronomy.com/extracontent**.

Irregular galaxy NGC 4449, also known as Caldwell 21, lies in the constellation Canes Venatici. If your seeing is good, an 11-inch scope will help you spot several concentrations of star-forming activity. The main one lies to the north (top), but a smaller one is just south of the galaxy's core. JOHN AND CHRISTIE CONNORS/ADAM BLOCK/NOAO/AURA/NSF

Elliptical M87 in Virgo is a colossal object with a mass in excess of 3 trillion Suns and a diameter that may reach half a million light-years. M87 also possesses a huge array of globular clusters, perhaps numbering in the tens of thousands. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

NGC 4262 (Hubble class $SB0_{2/3}$): *The Hubble Atlas* provides no examples of $SB0_3$, so we'll take a look at the next best thing. This galaxy in Coma Berenices has ansae (extensions) off its hub. A large stellar envelope surrounds them. Through 8-inch or smaller scopes, NGC 4262 would rate as one of the least impressive selections. Even through large amateur instruments, observations of the bar are rare.

Normal and barred spirals

The Sombrero Galaxy (M104; Hubble class Sa): This bright galaxy in Virgo is probably the most famous Sa galaxy in the sky. M65 and M96, both in Leo, also fall within this classification. M104 has a large central hub with a ring of dust and stars. The darkness of the former material gives this galaxy its hatlike appearance. If M104 were face-on, the dust ring would not be visible.

Bode's Galaxy (M81; Hubble class Sb): There are many bright Sb-type galaxies. The second-brightest (the Andromeda Galaxy ranks number one), M81, is circumpolar for locations north of latitude 21° north. This object is bright and large, and while the arms are fairly thin, they show some detail through large apertures. Through most telescopes at a dark site, you'll note the large size of the central hub in comparison to the overall disk.

The Whirlpool Galaxy (M51; Hubble class Sc): As we progress from Sa to Sb, a spiral's central hub shrinks relative to its disk. The category that follows is Sc. We can choose from many examples throughout the sky, but the Whirlpool Galaxy is a favorite. At magnitude 8.4, it is bright, and its pair of spiral arms is visible through an 8-inch scope. It's also easy to locate, 3.6°

TEN MORE GREAT GALAXIES IN HUBBLE'S ATLAS

Object	Class	R.A.	Dec.	Mag.	Dimensions	Page
M33	Sc	1h34m	30°40'	5.7	67.0' by 41.5'	36
LMC	Irr. Type 1	5h24m	–69°45'	0.4	660' by 550'	38
NGC 3065	$S0_2$	10h02m	72°10'	12.5	1.8' by 1.7'	5
NGC 3077	Irr. Type 2	10h03m	68°44'	9.8	5.5' by 4.1'	41
NGC 3109	Irr. Type 1	10h03m	–26°10'	9.8	16' by 2.9'	39
Leo I	E0 dwarf	10h08m	12°18'	12.0	15' by 12.5'	3
NGC 3377	E6	10h48m	13°59'	10.4	4.1' by 2.6'	1
NGC 4636	E0	12h43m	2°41'	9.5	7.1' by 5.2'	1
NGC 5101	$SB0_3$	13h22m	–27°26'	10.6	6.0' by 4.1'	42
NGC 7741	SBc	23h44m	26°05'	11.3	4.0' by 2.7'	49

Key: R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude; Page = The page the galaxy appears in *The Hubble Atlas of Galaxies*

The Whirlpool Galaxy (M51), a face-on spiral in the constellation Canes Venatici, is one of the sky's true wonders. It shines relatively brightly for a galaxy at magnitude 8.4. To find it, aim your telescope 3.6° southwest of magnitude 1.9 Alkaid (Eta [η] Ursae Majoris). TONY HALLAS

southwest of Alkaid (Eta [η] Ursae Majoris) — the end of the Big Dipper's handle.

NGC 2217 (Hubble class SBa): The constellation Canis Major is not famous for the galaxies it contains, yet it has one of the best examples of an SBa. Although NGC 2217 has some features of an SB0 type, it has a conspicuous bar.

This galaxy also contains a bright inner disk with faint S-shaped arms resembling a lenticular. Its two arms are large, and they surround the inner disk, which contains nebulae and star clouds visible through a 20-inch telescope.

NGC 1300 (Hubble class SBb): The prototype of the barred spiral class lies in Eridanus, fairly low in the sky for northerly observers. NGC 1300 has open spiral arms of low contrast in comparison to the rectangular hub. NGC 1365 in Fornax is another example of this type, and while it does lie farther south, it is brighter, and its spiral arms are easier to see.

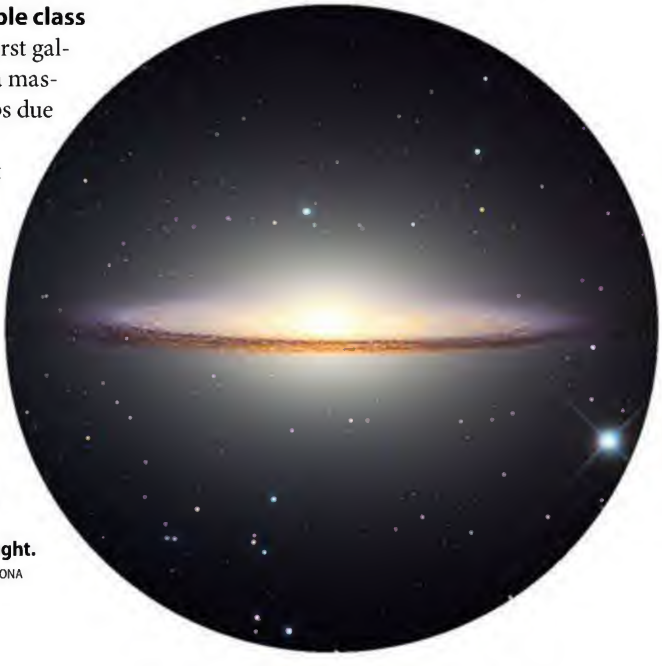
Irregulars

NGC 4449 (Hubble class Type 1 Irregular): This irregular galaxy resembles the Large Magellanic Cloud, one of the Milky Way Galaxy's satellite star systems. NGC 4449 has a boxy overall shape and a nonsymmetrical distribution of emission nebulae and star clouds. Through a telescope, it appears rectangular. Large instruments will reveal the patchy distribution of this galaxy's material.

The Cigar Galaxy (M82; Hubble class Type 2 Irregular): M82 is a starburst galaxy, a system that is experiencing a massive wave of star formation, perhaps due to a merger. It is indeed a cigar-shaped object with lots of dust that is easy to see even through small telescopes. The Cigar Galaxy differs from Type 1 Irregulars in that it contains more dust. Nearby NGC 3077 is another example of a Type 2 Irregular.

Just the beginning

These samples represent the tip of the iceberg. Each fits in Hubble's system, and all are worth a detailed look. So set up your scope and observe them. In a few sessions, you'll understand how one of the most famous astronomers classified galaxies.



The Sombrero Galaxy's (M104) lens shape and the dark dust lane that splits this spiral are easy to spot. The galaxy's two sections have unequal brightnesses — the north (top) outshines the south because M104 inclines 6° to our line of sight. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Dennis Mammana's cosmic portraits

This night sky photographer blends the terrestrial with the celestial to share the wonder and mystery of the cosmos. **text and photographs by Dennis Mammana**

It was a warm, starry night in the mid-1960s, and, as was my custom, I was in my Easton, Pennsylvania, backyard peering skyward with my telescope. Suddenly, through an open kitchen window, I heard my dad whisper to my mom, "What the heck does that kid do out there all night anyway?"

There was silence. Apparently, my mom had no clue either.

It was at that moment I realized the difficulty of explaining why the universe fascinated me so, why it made me feel so alive and part of something so wonderfully grand. If I could somehow capture and share with others the magic I felt beneath stars, I was sure they would become equally enthralled.

But how?

I frequently marveled at all of the glorious photographs in astronomy magazines of the day and thought to myself, "How tough could that possibly be?" So, I saved some money from odd jobs and bought myself a used Kodak Vigilant Junior Six-20 bellows camera and tripod, and set out to capture the cosmos.

Dennis Mammana *is an astronomy author, lecturer, and photographer who works under the dark skies of Southern California's Anza-Borrego Desert.*

The sky erupts with an amazing display of the northern lights above the moonlit Talkeetna Mountains southeast of Alaska's Denali National Park. The bright planet Jupiter lies to the lower right of the overexposed gibbous Moon. The author captured this scene March 23, 2002, combining seven overlapping wide-angle images.

The author frequently captures his night sky photos from Southern California's Anza-Borrego Desert, but he also travels all over the world to bring images of amazing celestial phenomena like solar eclipses and the northern lights to the public.

This all-sky photo of the northern lights above a resort outside Fairbanks, Alaska, on March 12, 2012, shows three different forms of aurorae: "Patches" are visible low toward the south (bottom in this image), a wide green "band" appears higher in the south, and the eerie "black aurora" (mysterious voids in which the aurora doesn't appear) lie overhead.

First light

My first attempts at night sky photography weren't terribly elaborate. I would load the camera with Kodak Tri-X roll film, park it in the backyard after dark, open the shutter, and return before dawn to harvest the star trails I hoped the camera had recorded. Sure, these first images weren't great, but I could process my own film while learning how much fun — and challenging — this activity could be.

Each winter, the author travels to the frozen tundra of Alaska to capture the northern lights. Here he photographs a beautiful auroral display from a site near Wickersham Dome north of Fairbanks, Alaska.

MAMMANA'S LAWS OF NIGHT SKY PHOTOGRAPHY

First Law: If you can see it, you can photograph it. A camera with manual settings and a tripod are all the gear you need to capture that wonderful scene you see in the night sky.

Second Law: Taking a sky photo is easy; taking a great one, however, is tough. Beautiful night sky photography requires a bit more skill and practice than you might think, but it's not brain surgery. You can do it!

Third Law: If it's too bright, darken it. If it's too dark, brighten it. Don't be afraid to experiment with your camera's manual settings. Only by accident will you get it right the first time.

Fourth Law: One muffed sky photo requires the purchase of two new pieces of equipment. I don't know why this is true; it just is! — *D. M.*

The overexposed nearly First Quarter Moon appears among the stars of Taurus in this fairy-tale scene from the top of the mountain at a resort outside Fairbanks, Alaska. Jupiter shines brilliantly above the trees to the right.

Soon I had progressed to a 35mm single-lens reflex (SLR) camera, and I found that others were beginning to take notice of my work. In fact, this year marks the 45th anniversary of my first published photo.

The date was April 12, 1968, and somehow my father had arranged for me to shoot that night's total lunar eclipse with my hometown newspaper's photographer. Despite listening patiently to my advice about eclipse-shooting techniques, the photographer chose to trust his own sensibilities rather than believe some dorky 16-year-old. Later that night, we developed our film, and, well, his photos landed in the trash while mine appeared in the next evening's newspaper.

Changing times

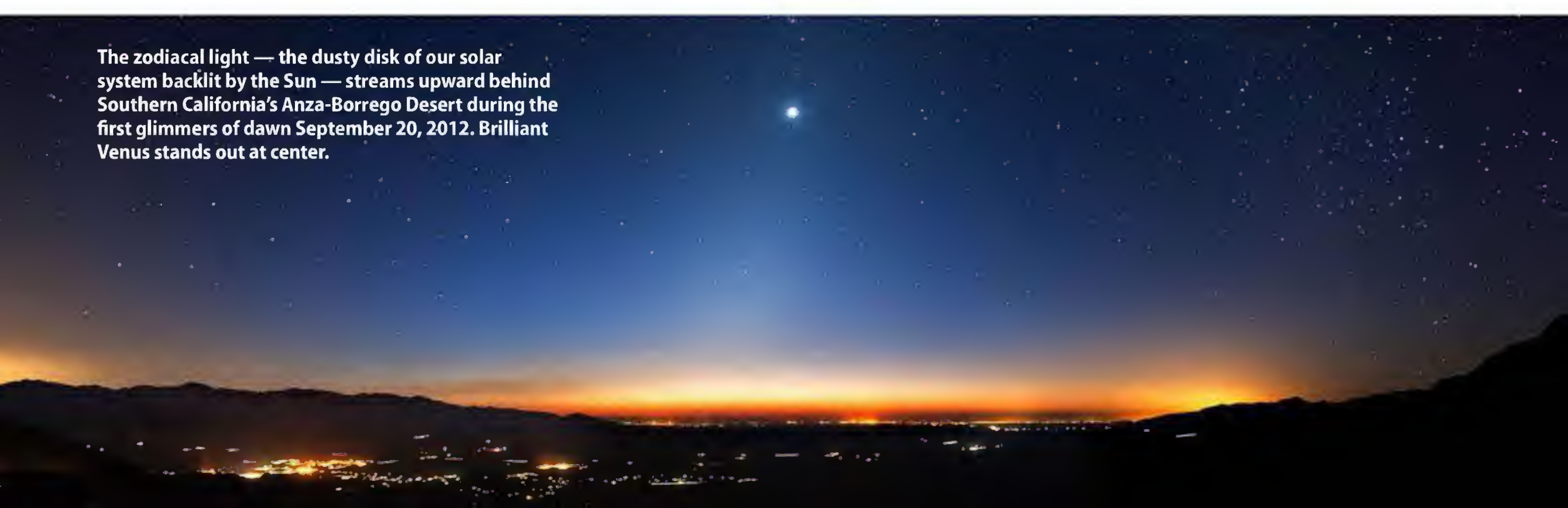
In the time since those eclipse photos, we have seen a stunning revolution in our ability to capture the cosmos. Although my gear has changed — today my main camera is a Nikon D700 digital SLR along with my workhorse lens, a remarkably sharp (and painfully expensive) AF-S Nikkor 14–24mm f/2.8G ED — my goals remain much the same. I wish to capture the color, motion, and majesty of the heavens in ways one rarely sees, and, by blending the terrestrial with the celestial, offer a unique sense of perspective and wonder. Achieving such goals, however, is not so easy.

During a single night, I may shoot dozens or hundreds of images, and if I come away with one that's really good, I'm quite happy. If I should find two or three, I'm ecstatic. But it's never immediately obvious; in fact, I'm rarely happy with what I see on

The Full Moon rises over the glistening waters of San Diego Bay. The author captured this image October 29, 2012, from the Old Point Loma Lighthouse on the southernmost tip of Southern California's Point Loma peninsula.

On the morning of July 22, 2009, the Moon appeared to drift in front of the Sun, creating a total solar eclipse over the Zhenjiang Pavilion in Yichang, China. The event allowed our star's outer atmosphere, the corona, to shine forth and caused the sky to take on the appearance of twilight. Mercury appears below the eclipsed Sun in this image.

A bright meteor flashes across the summertime Milky Way over Southern California's Anza-Borrego Desert on June 6, 2011. In the foreground are silhouettes of wild horse statues, two of dozens of life-size metal sculptures by the artist Ricardo Arroyo Breceda created at the request of land owner Dennis Avery on various parts of his property.



The zodiacal light — the dusty disk of our solar system backlit by the Sun — streams upward behind Southern California's Anza-Borrego Desert during the first glimmers of dawn September 20, 2012. Brilliant Venus stands out at center.

A crescent Moon lingers above a statue of Egyptian pharaoh Ramesses II in the ancient city of Thebes, a World Heritage Site at Luxor, Egypt.

An intrepid lunar eclipse campout group hovers over a toasty campfire beneath the Full Moon of December 9, 2011, hours before the event.

A towering tree in the mountains near Julian, California, provides a stark contrast to the twinkling lights of the Milky Way. The author had to wander some 75 yards off a path into thick knee-high grasses, careful to avoid snakes, to capture this image July 16, 2012.

the camera's LCD screen. Only after a few clicks and adjustments in *Lightroom* and *Photoshop* do I begin to realize what I've got. And then my reaction is, "Hey, this is pretty good stuff!"

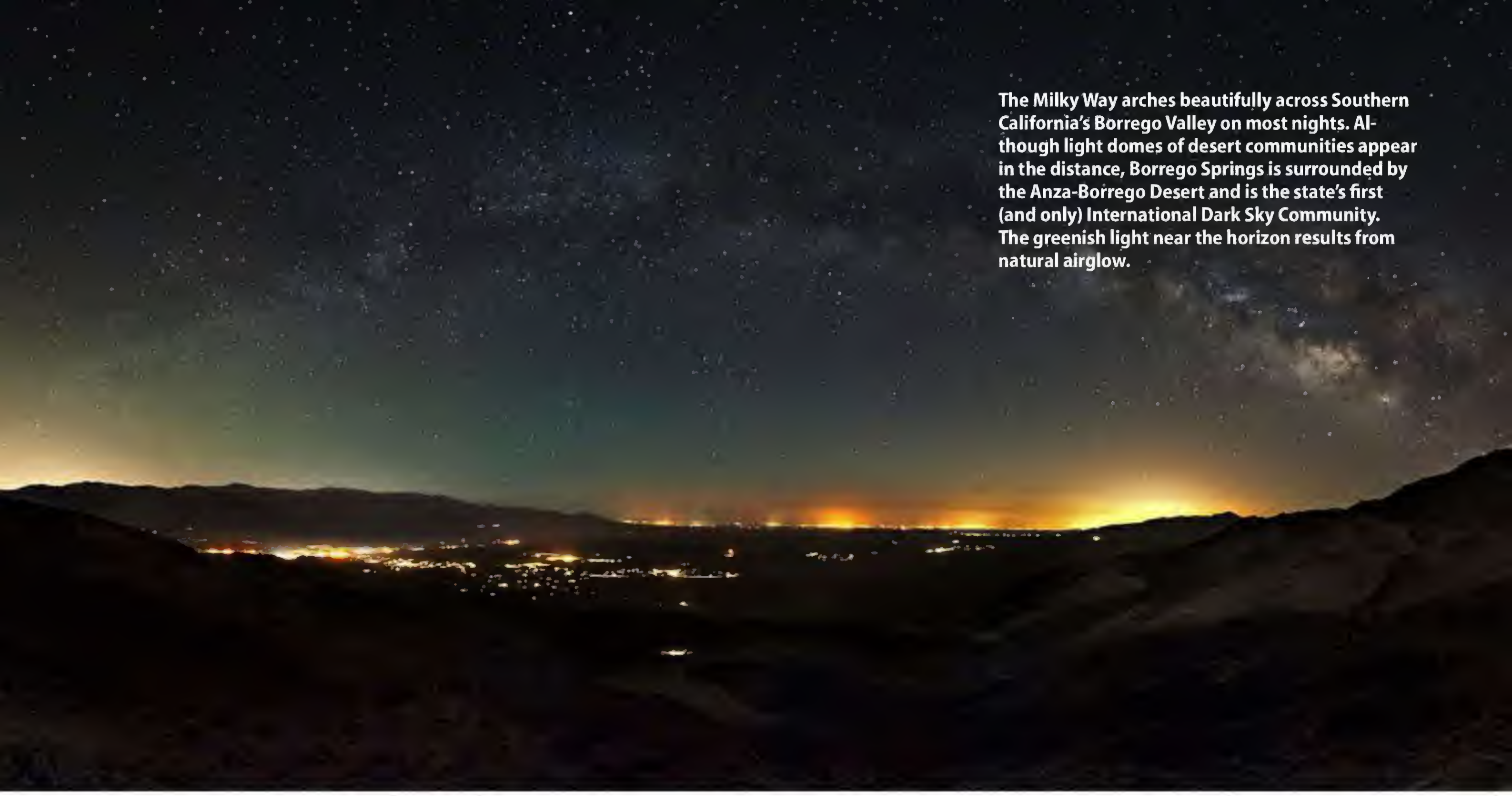
Sharing the cosmos

While I enjoy little more than seeing a new image I've just created, the pursuit is not just about taking photos; it's about sharing my knowledge and passion. What I call night sky photography — capturing wider scenes such as the Milky Way arching over a reflective lake or a spectacular desert moonrise behind wispy clouds — not only is achievable by anyone with a camera and tripod, but also creates a unique image with every exposure.

Since the mid-1980s, I've offered photography workshops around the country to inspire others to aim their cameras skyward. With the instant feedback of digital technology, today's participants can learn in only two days what took me decades.

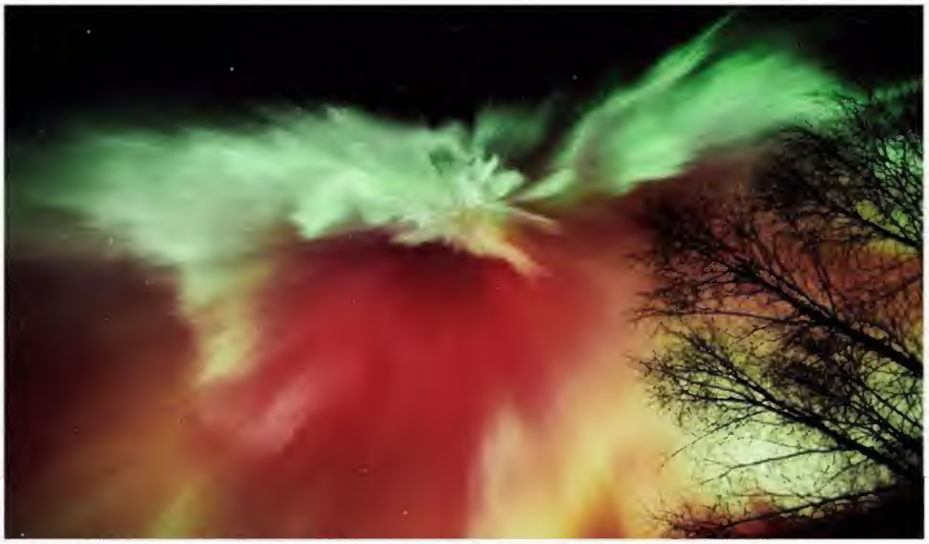
I also lead public tours around the globe to help others view and photograph such exotic phenomena as total solar eclipses, comets great and small, the northern lights, and more. In the process, I've managed to come away with a few good shots of my own.

But for all the sky shows that have performed before my camera, nothing can match the mystical dancing lights of the aurora borealis. Since 2000, I've traveled to the Arctic 19 times to stand slack-jawed in sub-zero temperatures while trying to capture what can only be described as the greatest light show on Earth.



The Milky Way arches beautifully across Southern California's Borrego Valley on most nights. Although light domes of desert communities appear in the distance, Borrego Springs is surrounded by the Anza-Borrego Desert and is the state's first (and only) International Dark Sky Community. The greenish light near the horizon results from natural airglow.

The light from the nearly Full Moon interacts with cloud droplets and high ice crystals in the desert sky to create the colorful scene of a lunar corona from August 15, 2008. This atmospheric phenomenon has an intensely bright central aureole that is almost white and fringed with yellows and reds.



On the night of March 23, 2001, the heavens over Fairbanks, Alaska, lit up with the most spectacular of auroral displays: a corona. A corona occurs when an auroral curtain appears at the magnetic zenith — which lies nearly overhead in Fairbanks — and viewers look up one of its long rays.

Coming full circle

Yes, it's an odd pursuit — heading into the darkness with my camera as others retreat to the comfort and safety of their homes, only to return home at sunrise, exhausted, to sleep the day away. Yet I know that if I can capture a sense of my celestial experience and bring it home to share with those not fortunate enough to join me under the stars, I will have achieved my goals. And, in the process, I will have confirmed once again the words of Grand Canyon pioneer Bessie Hyde: "We of the night will know many things of which you sleepers will never dream."

Nearly five decades after I first pressed a camera shutter, my need to share with others the exhilaration and connection I feel under the stars has now come full circle.

It was little more than a year ago that I was back in my hometown visiting my 98-year-old mother shortly before she passed away. I showed her some of my most recently published night sky photos, and as she pored over them with delight, I could only imagine the memories she must have been reliving of that young boy spending nights in the backyard doing who knows what under the stars.

And then, with such pride in her eyes, she looked up at me and said, "You're really alive when you're out doing this, aren't you?"

Indeed I am, Mom. Indeed I am!

SEE MORE IMAGES FROM DENNIS MAMMANA AT **www.Astronomy.com/toc.**

How to choose the right binoculars

When the time comes to observe with both eyes open, follow these tips and you won't go wrong. **by Mike Reynolds**

Through the years, many people have asked the *Astronomy* staff, as well as scores of amateur astronomers: "I want to buy my first telescope; which one should I buy?" After considering the needs of the questioner, we often respond, "Buy binoculars. Then, if your interest continues, buy a telescope."

The implication here is that binoculars will test a person's passion for the subject at a much lower price than a telescope. If the urge for astronomy wanes, binoculars will still prove useful in many circumstances.

But which binoculars are best for astronomy? And what characteristics should one look for when purchasing them? Such questions arise because the features that are best for our hobby are different from those for sports or birdwatching.

Why binoculars?

One reason for using binoculars is human physiology: We have two eyes. (The word *binocular* comes from the Latin term for two eyes.) There are benefits to using both eyes. First, it means more light reaches the brain; some scientific studies indicate up to a 40 percent increase. Second, resolution — the ability to see details or distinguish between two nearby objects — increases. Other reasons are that image contrast goes up and many observers are able to detect more color. Finally, using two eyes allows the brain to perceive near-stereoscopic images.

Celestron Skymaster binoculars magnify objects ninefold and have 63mm front lenses.

Binoculars are ideal for both the novice hobbyist and the experienced skygazer because of the low magnification and wide field of view. Above all, binoculars are portable. They are much easier to set up and use than telescopes.

The numbers game

One of the first binocular characteristics you will note is a set of numbers, like 7x50 (pronounced "seven by fifty"). The first number is the binoculars' magnification (or power). In this example, the unit magnifies sevenfold. That means any viewed object appears seven times closer than it is.

When considering magnification, seven is a good choice for general stargazing, whereas 10 and greater works well for solar system observing, viewing deep-sky objects, and splitting some double stars.

The second number in the 7x50 example is the diameter of each front lens in millimeters. So, our example has 50mm (approximately 2 inches) lenses.

Most manufacturers and observers call binoculars with front lenses larger than 70mm "giant binoculars." These units require a mount that allows them to fasten to a tripod. Magnifications above 7x require support because every wiggle and vibration becomes more pronounced when subjected to higher power. Also, such units are generally larger and heavier, so they're not as easy to hand-hold. You'll find a threaded hole on all binoculars that allows you to secure them to a mount.

Most models of zoom binoculars (those that have multiple magnifications) do not work well for astronomy. To make them zoom, manufacturers must introduce additional optics that decrease image brightness. Such units also are heavier and generally more expensive.

Mike Reynolds *is a contributing editor of* Astronomy *and dean of Liberal Arts and Sciences at Florida State College at Jacksonville.*

Binoculars use a combination of lenses and prisms to keep an object "correct" (the way you see it without optics). This image shows how the light passes through binoculars that use Porro prisms.

Inner workings

The binocular optical system is both similar and dissimilar to the one in a telescope.

Once you choose your binoculars, join the Astronomical League and observe a list of objects to earn a certificate. MICHAEL E. BAKICH

Cases, like this one for Zhumell's Tachyon 25x100 Astronomical Binoculars, offer protection against dust and abrasions. *ASTRONOMY*: WILLIAM ZUBACK

Both have a light-collecting element (each front lens in binoculars) and an eyepiece or eyepieces. But binoculars also include a prism system that takes the image and makes it "correct" (not inverted and/or reversed, as with telescopes).

Two conventional binocular prism systems exist: Porro (capitalized because its inventor was Italian optician Ignazio Porro) and roof. Porro prisms are of higher quality because manufacturers generally use a better grade of optical glass.

Other important binocular characteristics to consider include how the instrument focuses. Is the mechanism individual focus (IF) or center focus (CF)? IF systems, in which each eyepiece focuses independently, are less expensive. But even with a CF system, one of the eyepieces is adjustable, allowing for the observer to correct for differences in each eye. A few manufacturers also make fixed-focus models. Avoid them.

Optical coatings are another important consideration. They range from none to coated, fully coated, multicoated, and fully multicoated. The last option, in which each optical surface receives several coatings, is best for astronomical purposes. Such a process maximizes the light passing through and minimizes scattered light, which lowers contrast.

The devil's in the details

Three more numbers you'll want to know about your binoculars are exit pupil, eye relief, and field of view. Exit pupil is the diameter of the beam of light exiting the binoculars' eyepieces. Usually, the larger the exit pupil is, the better — with one caveat. As you age, the size your pupil attains when your eyes are dark adapted decreases, and you want to try to match your binoculars' exit pupil to your eyes. So, if you're under 40, go for a 7mm exit pupil. Over 60? A 5mm exit pupil probably will work well for you.

Eye relief is a measure of the distance from your eye to the eyepiece that enables you to see the entire field of view. The larger the eye relief, the easier it will be to see through the binoculars because you won't have to hold your eyes against the eyepiece lens. Look for eye relief in the 15mm to 20mm range.

Field of view is a measure of how much you can see through the equipment. Manufacturers specify it either as degrees or as the width in feet the unit shows at 1,000 yards. Choose the field of view that best fits your observing. If you look at meteor trails or aurorae, a wide field is best. For viewing star clusters or widely spaced double stars, a narrow view will do.

Beyond the numbers, any binoculars you choose should smoothly adjust for the distance between your eyes — called interpupillary distance. And ask yourself how the binoculars feel in your hands. Comfort while holding even lightweight binoculars is important. Remember, you're planning on some extended periods of viewing.

Other factors that may help you decide between two binocular types include whether they have rubber eyeguards (which keep stray light out), built-in (permanently attached) caps, and image stabilization and whether the unit is waterproof.

Be sure to talk to others who use binoculars for astronomy. A local club or science center will be a good source of information. Finally, try several models before deciding. You'll probably eventually own a couple of binoculars for different types of observing. An inexpensive unit will get you started observing, but high-quality binoculars will prove a lifetime investment and a valued companion.

Some astronomical binoculars, like the Vixen BT-125A, are too heavy to hand-hold. This unit (without the fork and tripod) weighs 24 pounds (10.9 kilograms). You'll need a mount. VIXEN OPTICS

Explore **11 spring binocular gems**

Grab your binoculars and peruse a globular cluster, double stars, and lots of galaxies. **by Phil Harrington**

Galaxies fill the springtime sky from across the depths of the universe. Most are so faint that they lie in the realm of the telescope only, but several do break the binocular barrier. In this article, I'll examine some of them as well as check out other spring celestial targets much closer to home.

Our first stop will be at three spiral galaxies that many observers know as the Leo Trio. **M65** and **M66** lie southeast of the star Chertan (Theta [θ] Leonis), which marks the right angle intersection in the triangle of stars forming Leo's back and tail. Joining the pair is **NGC 3628** just to the north.

I can routinely see M66 through my 10x50 binoculars from my suburban home, but M65 glows about half a magnitude fainter and requires a night with better-than-average transparency. NGC 3628 is even more challenging. You'll need at least 15x70 binoculars to spot this one. It also helps to brace the binoculars.

Next, head one constellation west to Cancer. Splitting most double stars requires a telescope, but you can split **Iota (ι) Cancri** with steadily held 10x binoculars — barely. Iota is the northernmost star in the inverted Y figure that forms the central shape of the Crab. The system's two stars have a separation of 31", just within reach of 10x binoculars. But the fun of it is the challenge. Give it a try tonight.

Next, let's move northward to Camelopardalis. Although the most luminous stars in this inconspicuous constellation are no brighter than 4th magnitude, it does host a fine spiral galaxy.

I've spotted **NGC 2403** through 10x50 binoculars from my backyard as an oval glow nestled near a triangle of faint stars. Yes, this one is also a challenge, but now is the best time of year to press your luck.

Spiral galaxy NGC 2403 in Camelopardalis is relatively bright for a galaxy, shining at magnitude 8.5. It's large, however, so that brightness spreads over an area defined by the galaxy's 25.5' by 13' dimensions.
ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Globular cluster M68 in Hydra shines at magnitude 7.3 and measures 12' in diameter. It's a tough catch through small binoculars, though.
DANIEL VERSCHATSE/OBSERVATORIO ANTILHUE, CHILE

Staying in the northern sky, let's survey a few targets in Canes Venatici the Hunting Dogs. First, scan for an eye-catching asterism of four stars that looks like a backward number 7 lying about a binocular field northeast of Cor Caroli (Alpha [α] Canum Venaticorum). Although the stars are not physically related to one another, they make a handy pointer that will lead you to the **Sunflower Galaxy** (M63). This spiral system will look like a tiny cigar-shaped blur, perhaps slightly brighter than M66. Can you catch it through your binoculars?

This constellation also holds a target for double-star fans. The stars **15 and 17 Canum Venaticorum** shine at 6th magnitude, creating a pair of identical celestial headlights pointing our way. It turns out, however, that 17 CVn, the easternmost of the two, lies just over 200 light-years from

---

Phil Harrington *is a contributing editor of* Astronomy *and author of* Cosmic Challenge *(Cambridge University Press, 2010).*

You'll find the Sunflower Galaxy (M63) in the constellation Canes Venatici the Hunting Dogs. It shines at magnitude 8.5 but spreads its light over an area measuring 12.6' by 7.2'. TONY HALLAS

Centaurus A (NGC 5128) has a magnitude of 6.8, but it's also more than 0.5° across, so its surface brightness is low. You'll need to observe from a dark location to spot it through binoculars. KEN CRAWFORD

Earth. But you would need to continue another 900 light-years through interstellar space before arriving at 15 CVn. So, while not a true binary system, the stars do form a pretty pair for springtime viewing.

Our last stop in Canes Venatici is **Upgren 1**, a seemingly rogue open star cluster you'll find 5° southwest of Cor Caroli. Discovered in 1963 by astronomer Arthur Upgren from Wesleyan University, Upgren 1 looks like a tiny triangle of faint stars through binoculars. Originally believed to be the remnant of an ancient cluster that subsequently scattered, astronomers now know that the stars are just a chance asterism. Cluster or not, Upgren 1 is still a fun sight through binoculars.

Spiral galaxies M65 (lower right), M66 (bottom center), and NGC 3628 are visible through large binoculars from a dark observing site. The Leo Trio lies in the constellation Leo the Lion. CHUCK KIMBALL

Next, head straight south to Coma Berenices, a constellation famous for its profusion of galaxies. But one stands out from the rest. **The Blackeye Galaxy** (M64) shines at 8th magnitude, so it's just in the range of 50mm binoculars. If, however, you are viewing through 80mm or larger binoculars, you might be able to catch its "black eye," a dark lane of dust silhouetted in front of this spiral galaxy's disk.

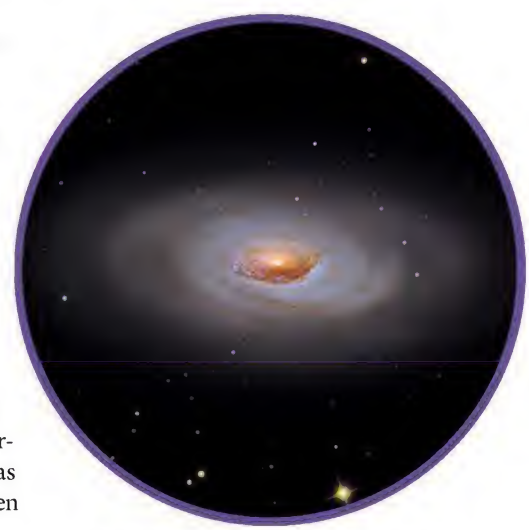
For our next object, continue your southward trek another 50°. Tucked beneath Corvus the Crow in an out-of-the-way corner of Hydra, globular cluster **M68** is a challenging binocular catch. But with patience, you'll be able to spot it.

And when you do, consider that when the light you're seeing from the cluster's 100,000 or so stars left there 33,000 years ago, early skywatchers near Blanchard, France, were engraving lines on animal bones to keep track of the Moon's phases.

Our final target this season can be easy, difficult, or impossible depending on where you are. That's because the bizarre galaxy **Centaurus A** (NGC 5128) floats 43° south of the celestial equator. Your best chance of spotting it is when it stands due south and is therefore highest in the sky. But how will you know when that is?

Luckily, the bright star Spica (Alpha Virginis) has nearly the same right ascension as the galaxy, so we can use it as a guide. When Spica sits on the meridian (due south), so does NGC 5128. From where I live on Long Island, I can just make it out through my 10x50 binoculars; my 16x70s improve the view immensely. Centaurus A is a powerful radio source that resulted from the merger of a huge elliptical and a smaller spiral galaxy.

Many more springtime binocular targets await us on the next clear evening. Head outside and enjoy all that the season has to offer. You'll soon know why I always say that when it comes to stargazing, two eyes are better than one.



The Blackeye Galaxy (M64) floats through the small constellation Coma Berenices and shines relatively brightly for a galaxy at magnitude 8.5. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

FIND 10 MORE SPRING BINOCULAR SIGHTS TO TARGET AT **www.Astronomy.com/toc.**

Astronomy tests the Telescope Drive Master

This easy-to-use device will smooth out your mount's tracking to make your images crystal clear. **by Mike Reynolds**

Attempting serious astronomical imaging requires three major components: the imaging device (a CCD camera or DSLR), the telescope (optical tube assembly), and the mount. All three must be of solid quality; one bad component is all it takes to doom the effort to subpar results.

Usually, those new to the hobby focus on the imaging device and the optical tube assembly; the mount is an afterthought or too pricey to consider at all. An excellent German equatorial mount (GEM), capable of superb tracking with minimized periodic error (inaccurate tracking because of tiny mechanical imperfections) can easily set you back five figures. (See "Periodic error" on page 67.) Yet beginners typically overlook merely good GEMs, which cost only around $1,500.

In an attempt to bridge the gap between the excellent and good GEMs, Attila Mádai, CEO of the Hungarian company MDA-TelesCoop, has introduced the Telescope Drive Master (TDM). This product corrects a mount's periodic error without the need for an autoguider system, thus transforming a good mount into an excellent one or making an excellent mount even better. Explore Scientific from Springdale, Arkansas, is the TDM's distributor in the United States and Canada, and Meade handles orders everywhere else.

The Telescope Drive Master, from Hungarian company MDA-TelesCoop, is a novel way to correct periodic error, instantly improving the quality of your telescope's mount. ALL PHOTOS: MIKE REYNOLDS

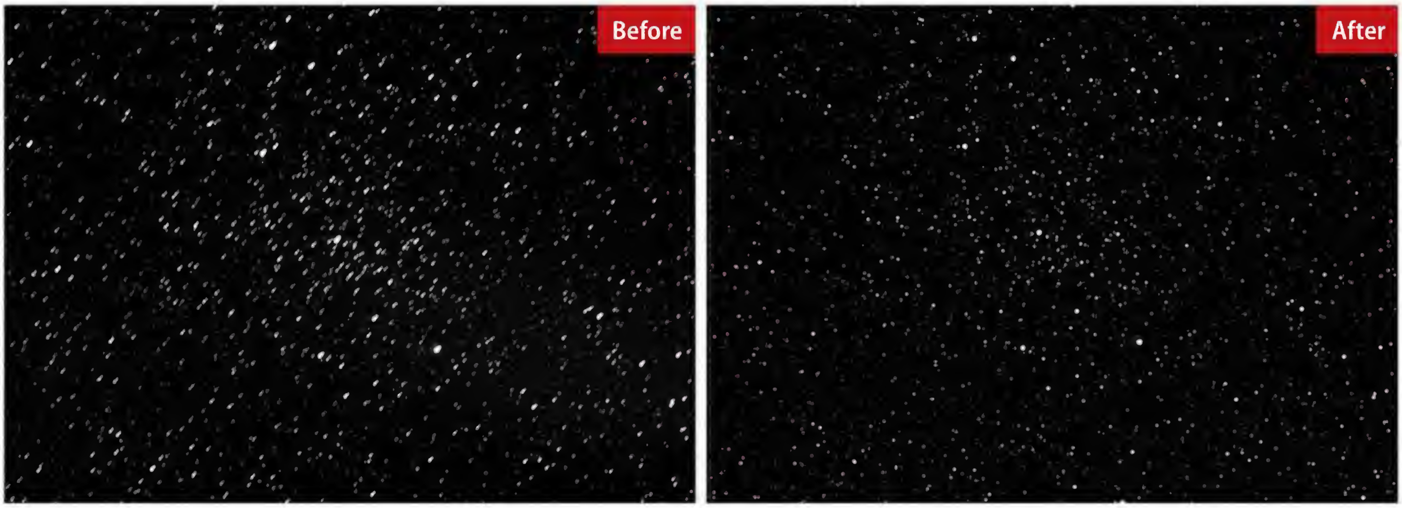
I tested the TDM on my Orion Atlas EQ-G GEM. This mount is a good one; I have used it visually with several optical tube assemblies and also for imaging. Yet it does suffer from periodic error (as do most mounts to some degree), so I was anxious to see if the TDM could truly transform my good mount into an outstanding one.

Precise setup

The TDM arrived from Explore Scientific neatly packaged, with the appropriate mechanical adapter for my equatorial mount. It's important to specify which mount you'll use with the TDM when ordering because each requires a specific mechanical adapter. (Luckily, the distributor has many available for commercial telescope mounts.)

The company included directions, which came complete with specific

The Telescope Drive Master's many parts are easy to install and understand, thanks to detailed and clear instructions. It proved to be a worthy addition to the author's astroimaging setup, removing errors and improving details.



Astroimages become clearer and display fewer errors with the Telescope Drive Master (TDM). Coupling the TDM with an autoguider system, as is now possible, would provide one of the finest tracking methods available: The latter handles atmospheric effects, and the former corrects everything else.

instructions and photographs for my setup, that were easy to follow. They helped me understand how the TDM components work with each other as well as with my mount and computer. Integrating the TDM with my mount was easy and took about one hour in total. Integration of the TDM's electronics control box with the mount system also was simple.

While installing the TDM, I had to remove my mount's polar axis alignment scope. This means that if I plan to install the TDM as part of a portable system, I also must include time to realign my setup immediately after finalizing installation.

Errors erased

I found that the TDM does indeed significantly reduce both periodic and nonperiodic tracking errors to within 0.5", a result agreeing with others' independent and rigorous tests.

This comes, however, with a couple of important caveats. First, the polar alignment must be extremely accurate. Second, these results don't hold for a poorly built GEM — the TDM cannot overcome errors in systems with a lot of flexure (pliability). And it's impossible to compensate for atmospheric refraction, which alters starlight before it even arrives at the scope.

Still, the TDM provided a marked improvement in tracking accuracy. To me, it was well worth the price as an addition to my Orion Atlas EQ-G mount.

A specific mechanical adapter is required to use the Telescope Drive Master, so be sure to specify while ordering this piece of equipment which kind of mount you'll use.

Improving on the best

The manufacturer has modified the latest versions of the TDM to integrate with an autoguider system. Coupling these two devices would provide an astroimager the finest in tracking: The autoguider compensates for atmospheric effects while the TDM corrects everything else during imaging sessions.

In pondering my results with the TDM, I thought about how it would perform with an expensive, high-quality GEM. Despite the utmost care by the manufacturer, all of these systems have some periodic error, so coupling the TDM with any of them would result in markedly improved quality.

So would I purchase the Telescope Drive Master? As a serious imager, absolutely! The TDM provides the opportunity, even when coupled with top-of-the-line equipment, to improve the chances of capturing the best possible image.

Just as imaging technology has undergone dramatic improvement in recent years, so have mechanical devices like the TDM — a tool amateur astronomers only dreamed of years ago.

Mike Reynolds *is an* Astronomy *contributing editor and dean of Liberal Arts and Sciences at Florida State College at Jacksonville.*

PERIODIC ERROR

Periodic error is a result of inaccuracies in a mount's right ascension gears. It's impossible to machine these gears precisely to keep the telescope on target at an affordable price, so minute spacing inaccuracies occur in the gear's teeth. As they rotate, these inaccuracies show up, especially during imaging. The unfortunate result: Instead of pinpoints, the imager gets blobby stars due to the mount's wobble. — *M. R.*

PRODUCT INFORMATION

Telescope Drive Master

Type: Tracking-error reducer
Dimensions: 5.5 by 5.5 by 1 inches (14 by 14 by 2.5 centimeters)
Shipping Weight: 5 pounds (2.3 kilograms)
Includes: TDM electronics unit, TDM encoder assembly, AC adapter, instructions
Price: $1,799.95
Contact:
Within the United States and Canada:
Explore Scientific
22 Sparrow Hill Lane
Laguna Hills, California 92653
[t] 866.252.3811
[w] www.explorescientific.com
Everywhere else:
MEADE Instruments Europe
Gutenbergstrasse 2
46414 Rhede, Germany
[t] +49 2872.8074
[w] www.meade.de

COSMIC**IMAGING**

BY TONY HALLAS

The right number of images

Let statistics work to the benefit of your pictures.

Most astroimagers know that if you take lots of frames and combine them, you get better results. The classic formula states that the gain in signal-to-noise ratio is equal to the square root of the number of frames combined.

But I have found that this is too simplistic. A lot of the time, we didn't have the best sky to work with or we misjudged exposure times. I used to think that a combination of the longest exposures and the most frames would give the best results. And in a perfect world, that would be true. In real life, however, this almost never happens. The reasons could be many. Some nights had bad seeing, others were cloudy, still others were too windy, etc. It's a long list! Knowing how outlier rejection (getting rid of all the things that don't belong in your picture, like cosmic-ray hits) and combining frames (to increase the signal-to-noise ratio) works is really important.

I use two kinds of rejection algorithms: Poisson Sigma Combine and STD Sigma Combine. You usually can find these in image-processing software like *CCDStack*. Both algorithms take a look at the statistics of your data and reject anything that falls outside parameters you choose. You can adjust the "attack" of this software to suit the degree of outliers in your image, but here is where you'll notice a subtle difference between the two processes.

STD Sigma Combine works best with lots of frames, whereas Poisson Sigma Combine works with as few as three frames. With identical settings, STD Sigma failed to remove a satellite trail when given three frames, but Poisson Sigma did. (See images below.) So, if circumstances limit you to only a few exposures, use Poisson Sigma to clean up your outliers.

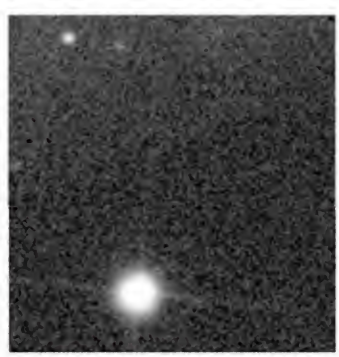
The mean (average) of a set of images works hand in hand with outlier rejection in two ways. First, the more frames you shoot, the more you dilute a particular outlier like a satellite trail. Average three frames together, and you will still see the trail; average 20 frames, however, and the satellite trail is now only one-twentieth that of the final image. It's been "diluted out." But there is a much more important reason to shoot a larger number of frames, and it has to do with statistics.

STD Sigma Combine is a fantastic outlier identifier, but it needs a lot of frames to build up a solid statistical model. So, the answer to the question, "Is it better to shoot just a few long exposures or a lot of shorter ones?" is the latter. Not only does this dilute what outliers might show up in your frames, but it also gives STD Sigma enough rejection frames to work properly. The pair of images below shows how much better twenty 15-minute frames are compared to just three.

The fact is that you can combine up to 25 frames before the asymptotic noise boundary (the noise that no amount of combining will eliminate) begins to impinge on the "square root/signal-to-noise formula." So, it is wiser to shoot a lot of shorter exposures and combine enough frames to allow statistics and the law of averages to perform their magic on your images.

It's truly all in the numbers.

Compare the image on the left, on which the author did a STD Sigma Combine of three exposures, to the right image, a Poisson Sigma Combine of the same three exposures. Note how the satellite trail disappeared with the latter algorithm. ALL IMAGES: TONY HALLAS



The left image shows a combination of three 15-minute exposures. Compare that to the right one, for which the author combined twenty 15-minute exposures. Notice how the 20-exposure stack reduced the overall noise.

FROM OUR INBOX

January kudos to Bakich

As I read the January issue this afternoon, I had to make a decision: Was I going to continue receiving this magazine or maybe try another one for a while? The article about gravitational lensing was very good, and of course I always enjoy Stephen James O'Meara's columns. Both the Voyager mission and Comet ISON articles also were awesome.

Then I came upon Michael E. Bakich's observing article, "What's lurking in Lynx?" I found it to be so interesting that I can hardly wait to observe the objects in his "tour." Right then and there, I put the issue down on the table, went online, and renewed my subscription. I don't want to miss a single issue. Thanks for such a great magazine. — **Carol Sabo,** San Tan Valley, Arizona

What a wonderful article in the January issue by Michael E. Bakich about "Voyager's 'new' solar system." I've been a big fan of this project since its launch in 1977; I often think of these two probes silently going "where no one has gone before" and from where they will likely send back information for at least 10 more years on their journey to the stars.

Obviously, there is always great interest in human trips into space, but I'd urge space fans to also follow Voyagers 1 and 2. The probes have overcome a history of glitches and now offer prospects for many more discoveries. — **Earl Finkler,** Medford, Wisconsin

BROWSE THE "COSMIC IMAGING" ARCHIVE AT **www.Astronomy.com/Hallas.**

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Wide-angle eyepiece

Meade Instruments, Irvine, California

The Meade Series 5000 Xtreme Wide Angle 14mm 100° Eyepiece features blackened lens edges and internal surfaces as well as a parfocal design for little focus change between eyepieces of the series. It offers a 100° apparent field of view.

Price: $399
[t] 800.626.3233
[w] www.meade.com

Astronomy app

Terminal Eleven, Albuquerque, New Mexico

Terminal Eleven's *SkyView* is an app for your iPhone, iPad, or iPod Touch. Simply point to the sky and tap on celestial objects to learn about them. The app provides an augmented look at your sky.

Price: $1.99
[t] 505.720.1832
[w] www.terminaleleven.com

Zoom eyepiece

Olivon USA, Roswell, Georgia

Olivon's 3X Deluxe 8–24mm Ultra Wide Angle Zoom Eyepiece features an apparent field of view from 43° to 66°, 15mm to 20mm eye relief, and a barrel that fits 1¼" or 2" focusers. The company fully multicoated all optics.

Price: $269
[t] 770.640.9692
[w] www.olivonusa.com

Observing planner

Knightware, Cary, North Carolina

Knightware's *Deep-Sky Planner 6* software for Windows has a database of more than 1.25 million objects. It helps you plan what to observe and when, generates multiple ephemeris reports, and gives up-to-the-minute information under the stars.

Price: $72 for digital delivery; $80.95 on CD
[e] presales@knightware.biz
[w] www.knightware.biz

5.1-inch go-to reflector

Orion Telescopes and Binoculars Watsonville, California

Orion's StarSeeker II 130mm GoTo Reflector Telescope features a 2" focuser with 1¼" adapter, 25mm and 10mm Kellner eyepieces, the company's EZ Finder II, an adjustable tripod, and *Starry Night* software. Its database holds 4,000 objects.

Price: $399.99
[t] 800.447.1001
[w] www.telescope.com

Computerized mount

Orion Telescopes and Binoculars Watsonville, California

Orion's Atlas Pro AZ/EQ-G Computerized GoTo Telescope Mount offers three options. It operates in equatorial mode holding one telescope or in alt-azimuth mode holding one or two scopes.

Price: $2,299.99
[t] 800.447.1001
[w] www.telescope.com

A+ SEE REPORTS ON 300+ PRODUCTS AT **www.Astronomy.com/equipment.**

INDEX *of* ADVERTISERS

The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

READER GALLERY

1. THE DEEP SKY IN ORION
NGC 2170 is the small emission nebula to the right of center. But the imager also caught a section of Barnard's Loop (Sh 2–276), a larger emission nebula that's part of the Orion Molecular Complex. (4-inch Takahashi FSQ-106EDX refractor at f/3.6, SBIG STL-11000M CCD camera, HαLRGB image with exposures of 90, 120, 60, 60, and 60 minutes, respectively) • ***John A. Davis***

2. THE FETUS NEBULA
Planetary nebula NGC 7008 sits in a lonely region of northern Cygnus the Swan. Large amateur telescopes and high magnifications often can pick up the knots intertwined within the gaseous sphere. (14-inch Officina Stellare RC-306AST Ritchey-Chrétien Cassegrain reflector at f/8, Apogee Alta U16M CCD camera, LRGB image with exposures of 280, 160, 160, and 140 minutes, respectively) • ***Bob Fera***

3

4

5

6

3. THE ROSETTE NEBULA
NGC 2237–9/46 pairs with open cluster NGC 2244 in the constellation Monoceros the Unicorn. Because narrowband filters, like the ones used here, dim the stars, the nebula's details really pop. (4-inch Stellarvue Raptor SVR105 refractor at f/7, Quantum Scientific Imaging QSI-583wsg CCD camera, Hα/OIII/SII image with twelve 20-minute exposures through each filter, stacked) • ***Craig and Tammy Temple***

4. THE WAR AND PEACE NEBULA
NGC 6357 is a huge emission nebula in Scorpius that covers 65 percent as much area as the Full Moon. It surrounds the magnitude 9.6 open cluster Pismis 24. (7.1-inch Takahashi Epsilon-180 Newtonian reflector at f/2.8, SBIG ST-10XME CCD camera, Hα/OIII/SII image with eleven 15-minute exposures through each filter, stacked) • ***Daniel B. Phillips***

5. COMET C/2012 K5 (LINEAR)
This visitor to the inner solar system had begun to fade from its brightest when the imager captured it here. The bright blue star at the bottom is magnitude 1.7 Elnath (Beta [β] Tauri). (8-inch Astro Systeme Austria ASA 8H astrograph at f/2.8, FLI PL-16803 CCD camera, LRGB image with 27-minute exposures through each filter) • ***Gerald Rhemann***

6. M81 AND M82
Bode's Galaxy (M81, left) and the Cigar Galaxy (M82) float through space in the constellation Ursa Major the Great Bear. Spiral M81 shines at magnitude 6.9 while starburst galaxy M82 glows at magnitude 8.4. (14.5-inch RC Optical Systems Ritchey-Chrétien reflector at f/8, Apogee Alta U16M CCD camera, LRGB image with exposures of 520, 220, 180, and 240 minutes, respectively) • ***Mark Hanson***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

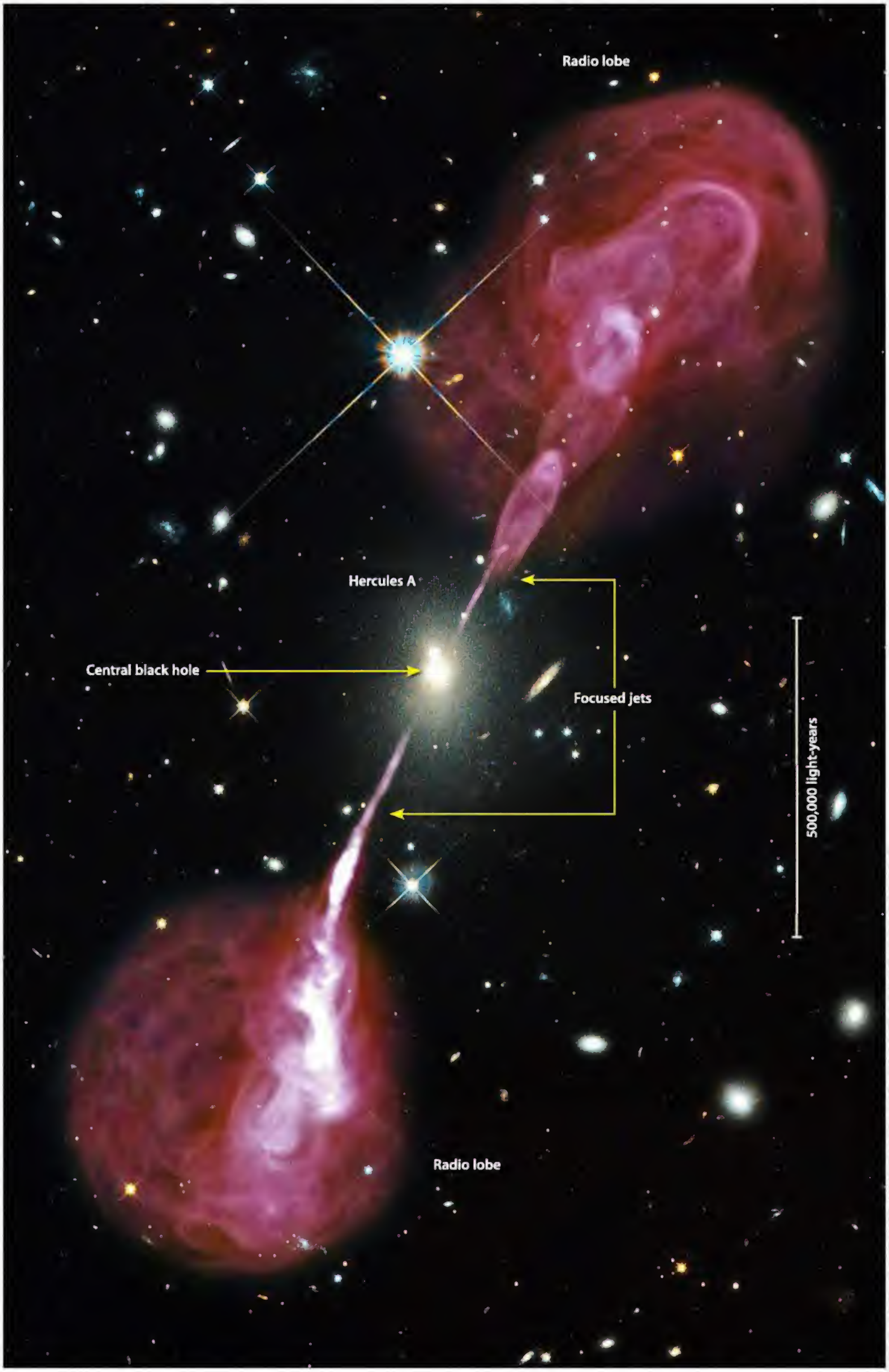
A close-up view of a monster

The giant elliptical galaxy Hercules A (3C 348) lies in the center of this new composite image made from Hubble Space Telescope imagery and data from the Jansky Very Large Array radio telescope. The combined view gives us a look at this monster galaxy, which spans several hundred thousand light-years and contains an immensely active black hole.

The jets of material are being shot away from the black hole's poles as material spins down into its abyss. As the material that escaped destruction flies away at high speeds, it slows and eddies into giant swirls of gas and dust on either side of the galaxy, visible as lobes of radio emission.

Despite the fact that astronomers have theorized black holes for more than 200 years, real proof of their existence has been elusive. Only in the 1990s did astronomers using the Hubble Space Telescope begin to find large numbers of black holes in the centers of galaxies.

It's now clear that nearly all normal galaxies — except for dwarfs — contain central black holes. The latter are only "active" when material falls in close to them; otherwise, they go quiescent and are relatively hard to detect.



NASA/ESA/S. BAUM AND C. O'DEA (RIT)/R. PERLEY AND W. COTTON (NRAO/AUI/NSF)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Ooo. Wow! Ahh!

It's not the fireworks on the fourth of July, it just sounds like it

Share *Your* Passion. Introduce someone to astronomy.

The following companies can help you get started.

ADORAMA
www.adoramacamera.com
212-741-0401
Qualified astronomers will help you find the telescope that's right for you. Visit our store online or in person for cameras, scopes and accessories.

CELESTRON
www.celestron.com
310-328-9560
Discover the Universe with Celestron and someone you love!

DAYSTAR FILTERS
www.daystarfilters.com
866-680-6563
Hydrogen Alpha filters. Designed to fit on any telescope. Dedicated Solar Telescopes from 60-100mm. The Academic Standard in Solar Bandpass Filters. Standard and professional grade. Celebrating 39 years.

EXPLORE SCIENTIFIC
www.explorescientific.com
866-252-3811
A manufacturer of fine scopes, eye pieces and accessories. We pride ourselves on our outstanding customer service and our outreach efforts. See our new traveling showroom at an event near you.

OCEANSIDE PHOTO & TELESCOPE
www.optcorp.com
800-483-6287
We will help you reach the stars. Full Service Astronomy Retailer. Amazing Service and Selection. "Respected by vendors. Trusted by Customers."

SANTA BARBARA INSTRUMENT GROUP
www.sbig.com
805-571-7244
SBIG is proud to support community outreach programs in science and astronomy. We support and applaud their efforts in reaching out to people of all ages.

SKIES UNLIMITED
www.skiesunlimited.net
888-947-2673
Visit us online or visit our retail store. Let a real astronomer help to choose the telescope that's right for you.

STELLARVUE
www.stellarvue.com
530-823-7796
We design, assemble and star test telescopes that provide and ensure razor-sharp, high contrast views of the universe. Don't compromise on quality, get the best and see the most.

VIXEN OPTICS
www.vixenoptics.com
949-429-6363
Share Your Universe with Vixen's quality products. Telescopes and Mounts for Observers of all ages.

WOODLAND HILLS CAMERAS AND TELESCOPES
www.telescopes.net
818-347-2270
We support dark skies everywhere. Come visit our store in Woodland Hills, CA or visit us online for details. Monthly Star Parties. Daily featured products online.

ASTRONOMY MAGAZINE
www.astronomy.com
800-533-6644
Astronomy magazine can help you learn about the night sky, and help you find the right products to begin the journey.

P18361

MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

July 2013: Venus returns to view

As evening twilight begins to fade, two bright planets deserve your attention. **Venus** comes into view first simply because it's so bright. At magnitude –3.9, it shines ten times brighter than the brightest star, Sirius. The planet gains considerable prominence this month because it climbs higher in the sky, firmly establishing its role as a western beacon that it will keep through year's end. Be sure to watch July 10 and 11, when it forms an attractive pair with a nearby crescent Moon.

Although Venus looks spectacular with naked eyes and binoculars, the view through a telescope proves disappointing. With an apparent diameter of 12" and an 87-percent-lit phase at midmonth, the planet looks like a small round ball. Nevertheless, Venus' gibbous phase was one of the strongest arguments Galileo used to support the Copernican idea that the planets revolved around the Sun and did not circle Earth.

Once you've had your fill of Venus, shift your gaze to the northern sky for a good look at **Saturn**. The ringed planet barely moves against the background stars of eastern Virgo, near that constellation's border with Libra. It stands a bit more than 10° east (to the right in our sky) of Virgo's brightest star, Spica. At magnitude 0.6, the planet shines slightly brighter than the star.

With Saturn high in the evening sky, it's a great time to target it with your telescope. During moments of good seeing, when Earth's atmosphere settles down and the image sharpens dramatically, the view is superb. Beginners typically are struck by how similar Saturn looks to pictures they have seen, but even experienced observers marvel at the magnificent rings. In July, these rings span 39" and wrap around a disk measuring 17" across. A 10-centimeter instrument reveals the rings' dark Cassini Division and at least four moons.

The three remaining naked-eye planets reside in the early morning sky and don't look nearly as nice as their evening siblings. **Jupiter** appears the most prominent, at least once it climbs higher later in the month. The largest planet stands barely 5° high in the northeast 30 minutes before sunrise July 15; by the 31st, it is nearly 10° high a full hour before the Sun comes up. Shining at magnitude –1.9, it shows up easily against the twilight glow. The giant world lies against the background of western Gemini, near the feet of the Twins and almost directly below the impressive figure of Orion the Hunter.

Turn your telescope on Jupiter and you'll see a dramatic world that spans 33" at the end of July. Although sharper views will come as it climbs higher in the months ahead, you should still see two parallel dark belts in the gas-giant's atmosphere and four bright moons.

Mars lies in the same part of the sky as Jupiter, but the magnitude 1.6 Red Planet will be much harder to spot in the twilight. The best day to look is July 22, when Mars passes 0.8° north of Jupiter. Binoculars will reveal a ruddy dot just below and to the left of the giant planet. A telescope at low power will show both, but don't expect to see any detail on Mars' 4"-diameter disk.

Our final morning planet is **Mercury**. The innermost world reaches inferior conjunction, when it passes between the Sun and Earth, on July 9. Afterward, it climbs into the twilight sky, where it attains greatest elongation July 30. It then lies 20° west of the Sun and appears some 5° high in the east-northeast 45 minutes before sunrise. The best way to find the planet is to search with binoculars to Jupiter's lower right.

The starry sky

The southern Milky Way stands out beautifully in July's early evening sky. If you face south once darkness settles in, Crux the Southern Cross along with Alpha (α) and Beta (β) Centauri — a pair of luminaries often referred to as "the Pointers" because they show the way to the Cross — dominate the scene.

Roughly 10° southeast (to the lower left on July evenings) of Alpha Cen and still within the Milky Way's glow lies the constellation Triangulum Australe the Southern Triangle. Its three brightest stars — 2nd-magnitude Alpha and 3rd-magnitude Beta and Gamma (γ) — form an obvious isosceles triangle aimed away from Alpha Cen. Although many other stars belong to this constellation, only 4th-magnitude Epsilon (ε) plays a significant role in the pattern — it lies almost exactly in the middle of the triangle's shortest side.

Several 16th-century observers saw a triangle in these stars, but the name Triangulum Australe didn't appear until 1603, when Johann Bayer included it in his *Uranometria*. The 17th-century German poet Caesius (Philipp von Zesen) perceived the stars as representing the Three Patriarchs: Abraham, Isaac, and Jacob.

The constellation's brightest star has a rather interesting proper name: Atria. At first blush, it might appear that the star reminded early stargazers of the chambers in the heart or the open-air courts in buildings. The namers were a bit cleverer than that, however, because they created the name by making a contraction of its designation — Alpha TRIanguli Australis.

Although the constellation is easy to find and lies in the Milky Way, it offers precious little to observe through a telescope. The best object is the open star cluster NGC 6025, which lies on the constellation's northern border with Norma the Square. This 5th-magnitude object contains several dozen stars, the brightest of which glows at magnitude 7.3. The cluster makes an attractive sight in a moderately wide-field eyepiece.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth

MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white unless magnified.

Illustrations by *Astronomy*: Roen Kelly

JULY 2013

Calendar of events

2 Pluto is at opposition, 0h UT

5 Earth is at aphelion (152.1 million kilometers from the Sun), 15h UT

6 The Moon passes 4° south of Mars, 12h UT

7 The Moon is at apogee (406,490 kilometers from Earth), 0h35m UT

8 New Moon occurs at 7h14m UT

9 Saturn is stationary, 4h UT

Mercury is in inferior conjunction, 19h UT

10 The Moon passes 7° south of Venus, 23h UT

16 First Quarter Moon occurs at 3h18m UT

The Moon passes 0.3° north of Spica, 4h UT

17 The Moon passes 3° south of Saturn, 1h UT

18 Uranus is stationary, 0h UT

20 Asteroid Flora is at opposition, 1h UT

Mercury is stationary, 14h UT

21 The Moon is at perigee (358,401 kilometers from Earth), 20h23m UT

22 Venus passes 1.2° north of Regulus, 5h UT

Mars passes 0.8° north of Jupiter, 6h UT

Full Moon occurs at 18h16m UT

25 The Moon passes 6° north of Neptune, 6h UT

27 The Moon passes 3° north of Uranus, 22h UT

29 Last Quarter Moon occurs at 17h43m UT

30 Mercury is at greatest western elongation (20°), 9h UT

Get the most in-depth astronomy magazine on the planet!

NASA/ESA/G. Illingworth and R. Bouwens (University of California, Santa Cruz)/The HUDF09 Team

Each monthly issue of ***Astronomy*** **magazine is packed with all the tools you need to unlock the mysteries of the cosmos. Whether you're a beginner or an experienced stargazer — *Astronomy* can help you enjoy every minute under the stars!**

Your subscription will include:

- Stunning images of the universe
- The latest in astronomy and space news
- Monthly columns from the best writers in the field
- Tips for locating stars, planets, and deep-sky objects
- All you need to know about the latest skywatching events

BONUS: Subscribers also get unlimited premium content on Astronomy.com!

Subscribe now *and* save!

Visit www.Astronomy.com

Outside U.S. and Canada, call 262-796-8776, x661

Mon.-Fri., 8:30 a.m.–4:30 p.m. CST. U.S. call 1-800-533-6644.

P18738

A35A